Impact of Soil Amended Superabsorbent Polymers on the Efficiency of Irrigation Measures in Jordanian Agriculture

Von der Fakultät für Lebenswissenschaften

der Technischen Universität Carolo-Wilhelmina

zu Braunschweig

zur Erlangung des Grades eines

Doktors der Naturwissenschaften

(Dr. rer. nat.)

genehmigte

D i s s e r t a t i o n

von Amjad Asri Abed Altarawneh

aus Al Karak, Jordan

1. Referentin oder Referent: apl. Prof. Dr. Robert Kreuzig

2. Referentin oder Referent: Prof. Dr. mult. Dr. h. c. Müfit Bahadir

eingereicht am: 22.10.2012

mündliche Prüfung (Disputation) am: 30.11.2012

Druckjahr 2012

<u>Vorveröffentlichungen der Dissertation</u>

Teilergebnisse aus dieser Arbeit wurden mit Genehmigung der Fakultät für Lebenswissenschaften, vertreten durch den Mentor der Arbeit, in folgenden Beiträgen vorab veröffentlicht:

Tagungsbeiträge

Altarawneh, A., Kreuzig, R., Batarseh, M., Bahadir, M. (2012): Impacts of Soil Amended Superabsorbent Polymers on the Efficiency of Irrigation Measures in Jordanian Agriculture. The 4th International Congress Eurosoil, Bari, Italy, 2-6 July.

ACKNOWLEDGMENT

First of all, whole praise and thanks is to ALLAH, the lord of all creatures who gave me the power to believe in myself and pursue my dreams. I could never have done this without the faith I have in you, the Almighty.

The present study was carried out in the Institute of Environmental and Sustainable Chemistry, TU Braunschweig, Germany, during the years 2009-2012 under the supervision of ***Prof. Dr. Robert Kreuzig****.*

I take immense pleasure to express my sincere and deep sense of gratitude to my supervising guide and mentor, ***Prof. Dr. Robert Kreuzig****, for his sustained enthusiasm, creative suggestions, motivation, excellent support and exemplary guidance throughout the course of my doctoral research. It has been an honor to be one of his Ph.D. students. Apart from the subject of my research, I learnt a lot from him, which I am sure, will be useful in different stages of my life. I solemnly submit my honest and humble thanks to him for bringing my dreams into reality.*

My sincere and profound gratitude to ***Prof. Dr. Müfit Bahadir****, the head of the Institute of Environmental and Sustainable Chemistry, TU Braunschweig, Germany, for his continuous support and encouragement during the period of my research and for giving me the opportunity to perform this work in Germany as a head of EXCEED project, and for his valuable time to follow, read and evaluate this study.*

It is my pleasure to express my appreciation and thanks to ***Prof. Dr. Dirk Selmar****, Institute of Plant Biology, TU Braunschweig, Germany, for accepting to be the chairman of the committee members of examination.*

It is not enough to thank the help and advice given by ***Prof. Dr. Dieter Zachmann****, Institute of Environmental and Sustainable Chemistry, TU Braunschweig, Germany, who gave me a lot of his time. His continuous support is highly appreciated and noted. He was an excellent supporter and never hesitates to support me with his knowledge and experience during the period of my study.*

I wish to extend my gratitude to ***Prof. Dr. Mufeed Batarseh,*** *the head of Prince Faisal Center for Dead Sea, Environmental and Energy Research, Mutah University, Jordan, for his continuous support and supervising this work during carrying out the field experiment in Jordan.*

Deep thanks to ***Prof. Dr. Khaled Khleifat,*** *the dean of Faculty of Science, Mutah University, Jordan, for his administrative and scientific support.* ***Prof. Dr. Farah Al-Nasir, Dr. Osama Mohawish, Dr. Adel Abdel-Ghani,*** *Faculty of Agriculture, Mutah University, Jordan, for their help and advices during this work.*

I offer my profound gratitude to Excellence Center for Development Cooperation ***(Exceed)****, German Federal Ministry for Economic Cooperation and Development* ***(BMZ)*** *and German Academic Exchange Service* ***(DAAD)*** *who financially supported this work. Special thanks also to the exceed entire staff members and organizers, especially,* ***Dr. Heike Dieckmann, Merle Mioch****,* ***Anja Breves*** *and* ***Jan Engelken*** *for their continuous help during the time of my scholarship within Exceed.*

I would like to extend my sincere thanks to ***Technische Universität Braunschweig****, Germany and* ***Mutah University,*** *Jordan, for supporting this work.*

I would like to express my deepest thanks to ***Mrs. Christiane Schmidt****, Institute of Environmental and Sustainable Chemistry, TU Braunschweig, Germany, for her scientific help, support and encouragement since the beginning of my study. I closely worked with her and I found in her a decent, kind and a greatly respective lady. I would like to thank her very much for introducing me to the instruments and for guidance during element analysis. Thanks also to* ***Mrs. Petra Schmidt****,* *Department of Geochemistry, Institute of Geoecology, TU Braunschweig, Germany, for her kind help in element analysis.*

My deep thanks to all my colleagues and all the entire staff members of the Institute of Environmental and Sustainable Chemistry, TU Braunschweig, Germany, for helping, providing a good working environment, working assistance whenever necessary, and for sharing their scientific knowledge. Special thanks to ***Sascha Pade*** *and* ***Ramona Stolte*** *for their honest and serious practical work during assisting me in the Institute of Environmental and Sustainable Chemistry, TU Braunschweig, Germany.*

Sincere thanks are also to the staff members in Prince Faisal Center for Dead Sea, Environmental and Energy Research, Mutah University, Jordan, for their help. Many thanks Also to Mr. Mohammed Alsarayreh for caring the field.

Thanks also to the Al Sultan Medical Labs, Amman, Jordan, represented by ***Mr. Amer Al Sultan*** *and* ***Mrs. Maha Alaeddin*** *for their help in bacterial study.*

Last but not least, I would like to thank all those, who helped me in a way or another during the preparation of this study. To the candles which light my way in this life; my parents, my soulmate ***Lama*** *who made this work possible through bearing the responsibilities of the family for three years with sacrificing, providing and supporting all the family with love and care, to the source of my inspiration and strength, my kids* ***Ahmad, Sadeen and Shahim****, my brother and sisters.*

Amjad Asri Al Tarawneh

Braunschweig, Germany, in October 2012

Dedicated to:

My parents,

My lovely soulmate Lama

My kids Ahmad, Sadeen and Shahim

Abbreviations

BOD_5	Biological oxygen demand
AWM	Artificial wastewater with intermediate heavy metal addition
AWMs	Artificial wastewater with high heavy metal addition
AWS	Artificial wastewater with intermediate salt addition
AWSs	Artificial wastewater with high salt addition
B.D	Below detection limit
BD	Bulk density
CFU	Colony forming unit
COD	Chemical oxygen demand
DO	Dissolved oxygen
DOS	Department of Statistics, Jordan
EC	Electrical conductivity
EPA	United States Environmental Protection Agency
FAO	Food and Agriculture Organization of the United Nations
FOG	Fat, oil and grease
FW	Fresh water
IC	Ion chromatography
ICP-OES	Inductively coupled plasma optical emission spectrometry
JICA	Japan International Cooperation Agency
JISM	Jordan Institution for Standards and Metrology
JMD	Jordan Meteorological Department
JVA	Jordan Valley Authority
MBAS	Methylene blue active substances
MOTA	Ministry of Tourism and Antiquities, Jordan
MWI	Ministry of Water and Irrigation, Jordan
n	Number of replicates
NB	Nutrient Broth
PAHs	Polycyclic aromatic hydrocarbons
PFC-DSEER	Prince Faisal Center for Dead Sea, Environmental and Energy Research
PWP	Permanent wilting point
SAP	Superabsorbent polymer
SAR	Sodium adsorption ratio
SD	Standard deviation
SIM	Sulfide-indole-motility

SIR	Substrate induced respiration
SPC	Standard plate count
TDR	Time domain reflectometer
TDS	Total disolved solids
TKN	Total Kjeldahl nitrogen
TOC	Total organic carbon
TSS	Total suspended solids
TW	Treated wastewater
USDA	United States Department of Agriculture
WAJ	Water Authority of Jordan
WHC	Water holding capacity

1. Introduction

1.1 Water scarcity in Jordan

Water scarcity is the most important natural constraint to Jordan economic growth and development. The proceeding desertification is of particular negative impact on the agricultural activities (Batarseh, 2009; Khleifat et al., 2006). Thus, desert areas represent today more than 90% of the total area of Jordan (Alqaisi et al., 2009). Adverse impacts are decreasing crop yields, irreversible degradation of productive soils, drastic reduction of farmland and grassland areas, and, finally, changes of socio-economic structures culminating in migration of the rural population into the cities. Therefore, proceeding desertification has to be counteracted by irrigation measures. For this purpose, the limited water resources have been already exhaustively used until today. Agricultural irrigation is the primary water-consuming sector followed by the municipal and industrial sectors. Nowadays, more than 63% of fresh water resources are used for agricultural production in Jordan (Hadadin et al., 2010; Al Nasir and Batarseh, 2008). 73% of the total water consumption was estimated to be used for agricultural, 22% of water for domestic and 5% for industrial needs (Al-Zboon and Al-Ananzeh, 2008). An assessment by Uleimat (2011) indicated slightly different numbers, with a total Jordanian water consumption of 941 Million m^3 in 2009, where 64% was used in agriculture **(Figure 1.1)**. It is expected that by 2020 the portion of fresh water allocated for irrigation will drop in order to ensure the water demand of municipal and industrial consumers (Metap, 2001). Therefore, it is the strategy to enhance the use of treated wastewater for irrigation measures in order to sustainably save fresh water reservoirs.

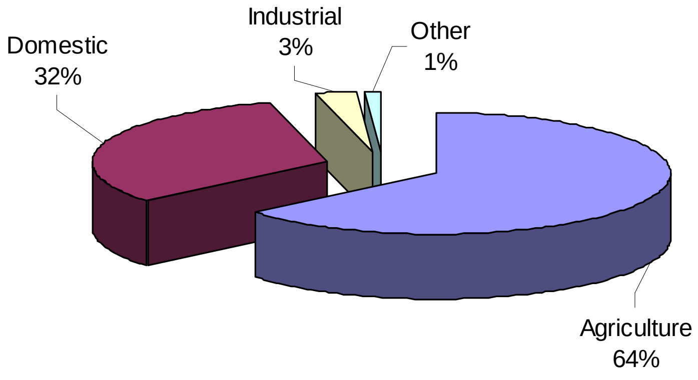


Figure 1.1: Water consumption in Jordan for the year 2009 (Uleimat, 2011)

1.1.1 Geography, climate and rainfall

The Hashemite Kingdom of Jordan is located at the east of the Mediterranean Sea, between $29^o.33´$ (north) and $32^o.55´$ (north), with a surface area of 90,000 km^2, and borders Syria to the north, Israel and the West Bank to the west, the Red Sea to the south, Saudi Arabia to the southeast and Iraq to the east (**Figure 1.2**). Jordan climate is classified as a mix of Mediterranean and dry desert climate which is characterized by low rainfall and high evaporation, where 92.2% of the rainfall evaporates (**Figure 1.3**) (Ammary, 2007; Batarseh et al., 2003; Al-Bashabsheh, 2007). The year is divided into two main seasons: a hot dry summer and a cool and relatively humid winter. The temperature varies from a few degrees below zero in the mountains in the winter to around 46 ^oC in Dead Sea Valley in the summer season (Ammary, 2007; Bani-Domi, 2005).

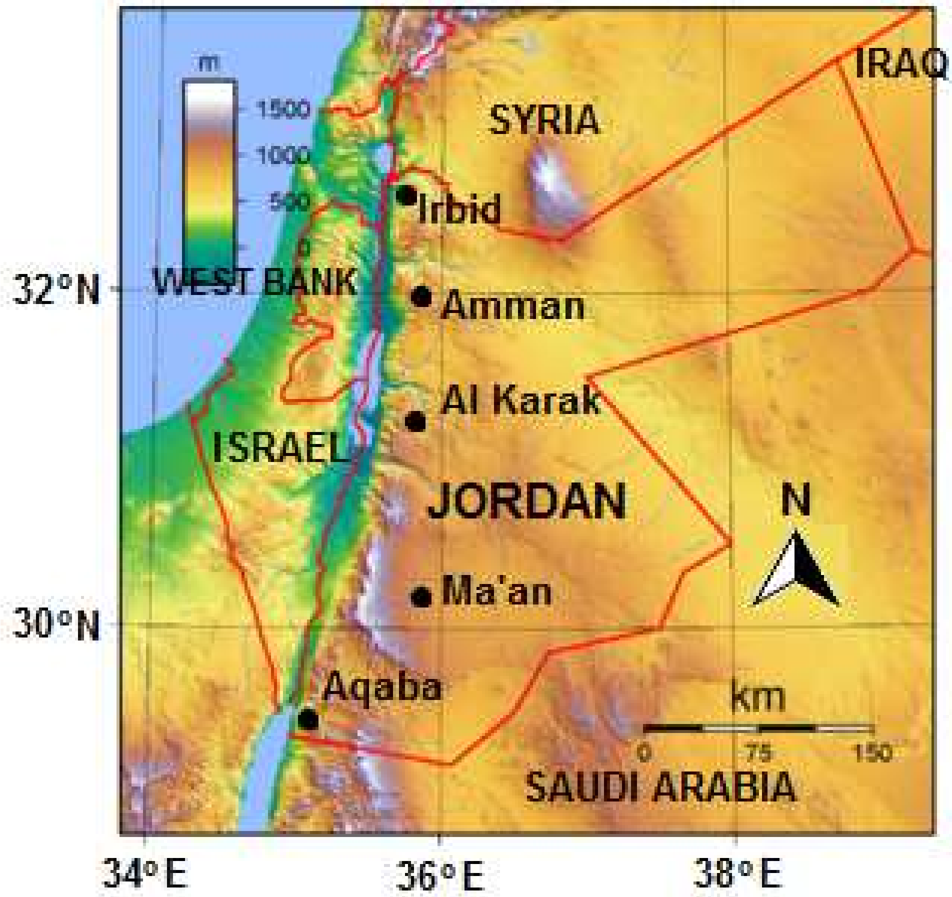


Figure 1.2: Location and geography of Jordan (Jordan Memory Tours, 2012)

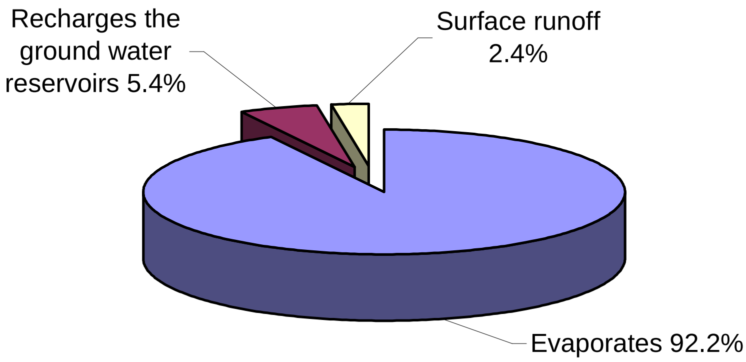


Figure 1.3: Ratio of rainfall recharges for the aquifer in Jordan (Ammary, 2007)

The Jordanian physiographic features and location have a great effect on spatial distribution and climatic variability. These major physiographic regions are very clearly distinguishable, from north to south direction. The eastern plateau rises rapidly in the west from below sea-level in the Jordan valley (200-410 m) up to elevations of more than 1200 m above sea level in the south, then descends gradually to 800 m above sea level eastward until merge with the desert, the last physiographic region (Bani-Domi, 2005). The mean of annual rainfall in Jordan has a close relationship with the regions. The rainfall decreases from west to east and from north to south. The annual mean rainfall in Irbid (north) is 486 mm, Al- Safawi (east) 86 mm, Ras-Muneef (west) 620 mm and Aqaba (south) 39 mm (Bani-Domi, 2005). According to Jordanian meteorological department (JMD) (2004), the consolidated rainfall average of 22 stations with long record over 60 years during the period 1944-2004 demonstrates an average rainfall of almost 350 mm/year (**Figure 1.4**).

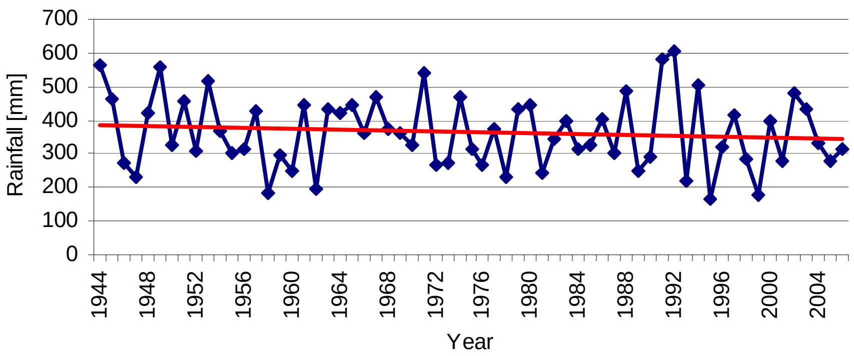


Figure 1.4: Fluctuation of annual rainfall precipitated over Jordan during 60 years (JMD, 2004)

The annual precipitation varies from 50 mm in the desert to 600 mm in the northwest highlands (Ammary, 2007). 90% of Jordan's total area receives < 200 mm rain per year, more than 70% receives < 100 mm and only 2% has an annual precipitation exceeding 300 mm. This higher precipitation occurs particularly in the north-western highlands (Raddad, 2005). As a comparing example, **Figure 1.5** shows temperatures and precipitation between the annual rainfall in Amman, Jordan, and Berlin, Germany. The annual rainfall in the year of 2006 was 590 mm and 274 mm in Berlin and Amman, respectively. The mean of temperature through the year was 8.6 ^{o}C and 17.5 ^{o}C in Berlin and Amman, respectively. On one hand the rainfall in Berlin was only two times more than in Amman, but on the other hand, the temperature in Amman is two times higher than in Berlin (**Figure 1.5**). The high evaporation in Jordan reduces the availability of the precipitation by about 90%.

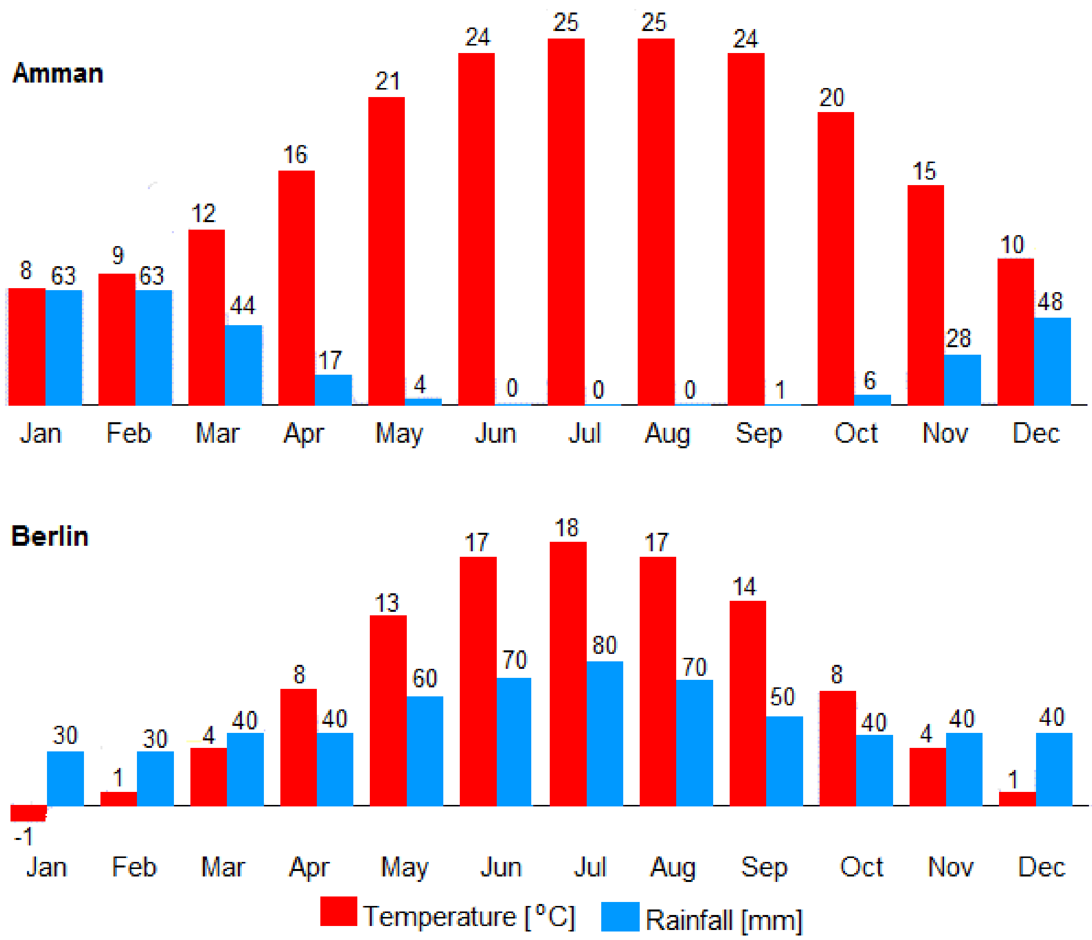


Figure 1.5: Average value of rainfall and temperature per month during the year of 2006 in Amman and Berlin (Countries of the world, 2006).

1.1.2 Water resources

Water scarcity and shortage is an ever-increasing worldwide challenge. The scarcity of water is the gravest environmental challenge faces Jordan these days. The expanding population, climatic and topographical conditions of Jordan have produced enormous pressure on the limited water resources and created a severe water supply-demand imbalance where the renewable water resources are among the lowest in the world, and is declining with time. This situation has been exacerbated by the fact that the current water use in Jordan exceeds renewable water supply by the unsustainable practice of overdrawing highland aquifers resulting in lowered water tables and declining water quality (Hadadin et al., 2009; Mohsen, 2007). The total water demand through the last 7 years and the expected demand for the next 8 years in Jordan is much more than the total water resources with deficit percentage varies from 25-45% (**Table 1.1**).

The reality of increasing water shortage in Jordan is the drying up of streams, falling ground water levels across the kingdom and the implementation of a rationing system has become necessary. The citizens get water from public supplies just one or two days a week (Hadadin et al., 2010). In addition, Jordan shares most of its surface water resources with neighboring countries which partially deprived Jordan of its fair share of water.

Table 1.1: Development of water resources and demands [million m^3/year]

Year	2005	2010	2015	2020
Renewable groundwater	259	259	259	259
Surface water	404	433	419	382
Treated wastewater, not flowing into reservoirs	69	101	89	34
Additional resources	511	456	454	344
Total resources	**1244**	**1250**	**1220**	**1019**
Municipal, industrial, tourist demands	493	634	561	433
Agriculture including reuse schemes	1120	1052	1101	1114
Total demands	**1612**	**1686**	**1661**	**1546**
Groundwater return flows from losses	63	63	62	66
Deficit	**-306**	**-373**	**-379**	**-461**
Deficit [%]	-25%	-30%	-31%	-45%

Source: Ministry of water and irrigation, National Water Master Plan (NWMP).

Surface water

Surface water resources constitute two-thirds of usable water resources in Jordan. At the present, surface water is used exclusively for agriculture, except for the spring water, which is collected for municipal use. The Jordan, Zarqa and Yarmouk are the three major rivers in Jordan. The Jordan and Zarqa Rivers are saline. The Zarqa River receives large amounts of municipal effluents. Therefore, the water can not be used directly for drinking but can be used for irrigation so far the national standards of irrigation water are complied. The Yarmouk River is also a sink for municipal wastewater but with less pollution (Abu Taleb and Salameh, 1994). Moreover, the major resources of surface water in Jordan are the Jordan River and Yarmouk River. Both rivers were depleted by upstream diversion and over-pumping in Syria and Israel that affected the quantity and quality of the Jordan's water share (Wardam, 2004). Yarmouk River is located at the borders with Syria. It is the largest source of external surface water with 40% of the surface water resources in Jordan and also the main source of water for the King Abdullah Canal. In addition, it is the main source for irrigation in the Jordan Valley (FAO Aquastat, 2008). Due to urbanization, upstream uses and climatic changes, the total flow of the Yarmouk River and the Jordan River dropped drastically (Wardam, 2007).

Groundwater resources

Groundwater contributes approximately 54% to total water supply in Jordan. The Jordanian groundwater occurs in 12 major basins, which are mainly concentrated in the Yarmouk, Amman-Zarka and Dead Sea basins. They produce total renewable groundwater resources, with an estimated volume of 500 million m^3/y. Another 220 million m^3 come from the base flow of the rivers (FAO, 2008).

According to the FAO statistics, the estimated safe yield for regenerating groundwater resources in Jordan is 275 million m^3/y. Currently, most of the groundwater is exploited at maximum capacity and far below the safe yield. 6 of the 12 groundwater basins are practically over-extracted, 4 are in-balanced and 2 are under-exploited. The main non-renewable aquifer is the Disi aquifer which fossil water in sandstone horizons, in southern Jordan with a safe yield estimated at 125 million m^3/year for 50 years.

Groundwater is considered as the main source for domestic water supply. However, this groundwater is in competition with the agricultural sector that consumes 70% of the water resources (Wardam, 2004). Over-extraction of groundwater resources led to degradation of water quality by increasing the salinity and reducing the exploitable quantities due to the decline of water levels, resulting in abandonment of many municipal and irrigation water well fields (FAO, 2008).

Rainfall

Rainfall in Jordan occurs usually between October and May. The total rainfall in Jordan is estimated at 8.5 billion m^3, of which about 92.2% is lost by evaporation (Hellenic, 2011). Limited amounts flow into rivers and wadis as flood flows and recharges groundwater. It is estimated that about 5.4% recharges the groundwater and the rest 2.4% goes to the surface water as mentioned by Ammary (2007). **Table 1.2** represents the water budget of Jordan during 1937-2005 (WAJ, 2006). Ta'any and Al Zu'bi (2007) mentioned the variations of the annual rainfall over a wet period of 9 years and over 10 years for dry periods. Their observations indicate larger variation of the period of drought than that of wet years.

Table 1.2: Water budget in Jordan during the period 1937 to 2005 (WAJ, 2006)

Rainfall	Evaporation		Runoff		Recharge	
volume (mm)	Amount	[%]	Amount	[%]	Amount	[%]
8338.5	7707.1	92.4	196.7	2.4	434.7	5.4

1.1.3 Population growth

The Jordan population grew from an estimated number of 586,000 people in 1952, to 900,800 in the first population census of 1961 and to 2,133,000 in the second census by 1979. The latest census in 2006 demonstrated that the population of Jordan was about 5.9 millions, and it is still increasing annually by 2.4% (DOS, 2006). According to the Department of Statistics report of 2010, the population of Jordan was 6 millions (**Table 1.3**) of which 82% live in urban areas. 90% of the population lives in the central and northern areas of the country and 39% in the capital Amman. The recent migration flows as well as the 70% of Jordan's population being under an age of 30 years have the combined effect of a high population growth rate. The total population could reach 8 million by 2020. This growth causes a significant pressure on public services and on water resources.

Figure 1.6 shows the comparison between Jordanian and German annual percentage of population growth rates. Whereas water resources in Jordan decrease, the population continues to rise. **Figure 1.7** shows that the municipal water consumption increased within 17 years from 115 million m^3/y to 250 million m^3/y causing a negative impact on the limited water resources (Shatanawi et al., 2008). On a per capita basis, Jordan has one of the lowest levels of water resources in the world (Ammary, 2007). The annual per capita water budget in Jordan is about 180 m^3/y (Nazzal et al., 2000), which is very low if compared to the international per capita consumption level of 1000 m^3/y (Al-Zboon and Al-Ananzeh, 2008). It is expected by the year 2025, if Jordan's population continues to rise the capita water supply will fall from the 145 m^3/yr in 2010 to 91 m^3/y and Jordan will be categorized within the category of absolute water shortage (Hadadin et al., 2010).

Table 1.3: Population information (DOS, 2010)

	1970	1980	1990	2000	2005	2009
Population [millions]	1.5	2.2	3.5	4.9	5.5	6.0
Population density [Inhabitants/km^2]	16.9	25.1	39.0	54.6	61.5	67.2
Urban population [%]	-	-	78.7	78.7	82.0	82.6

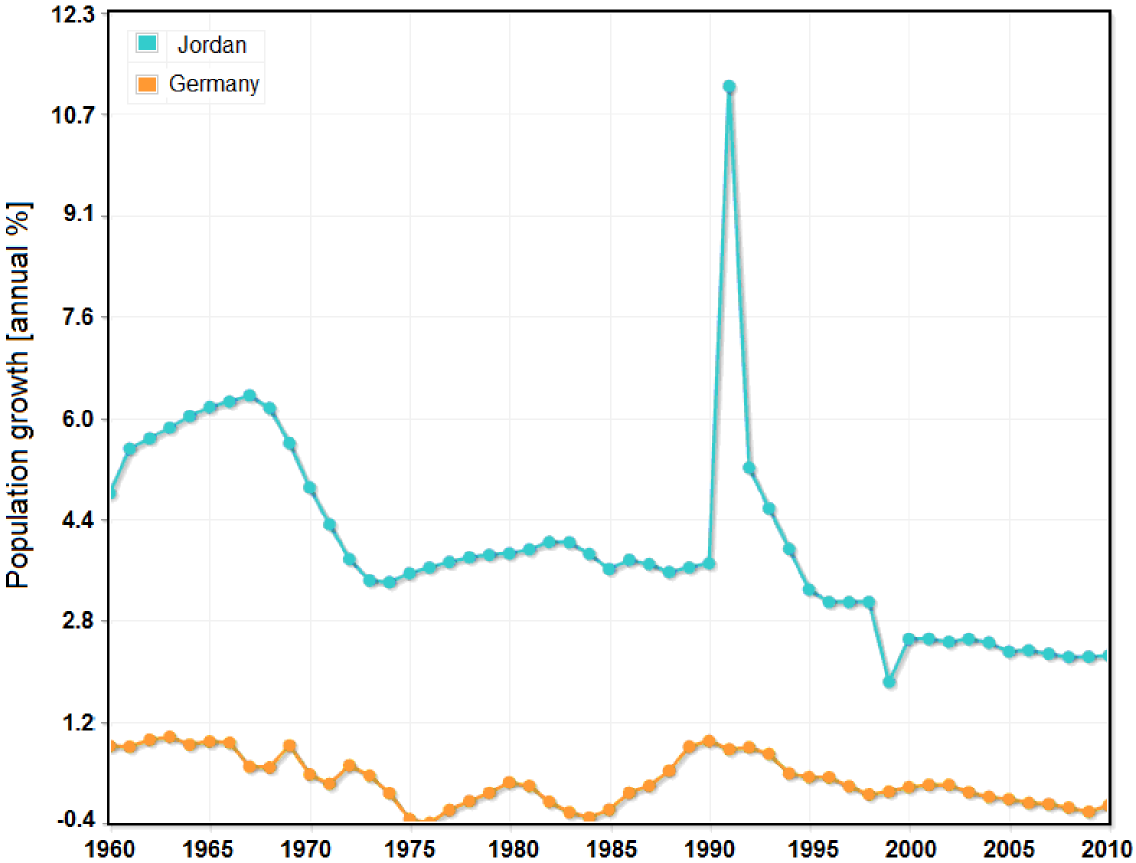


Figure 1.6: Annual percentage of population growth rate in Jordan and Germany. The high peak between 1990 and 1995 was as a reason of population influxes of the Gulf war (World Bank, 2011).

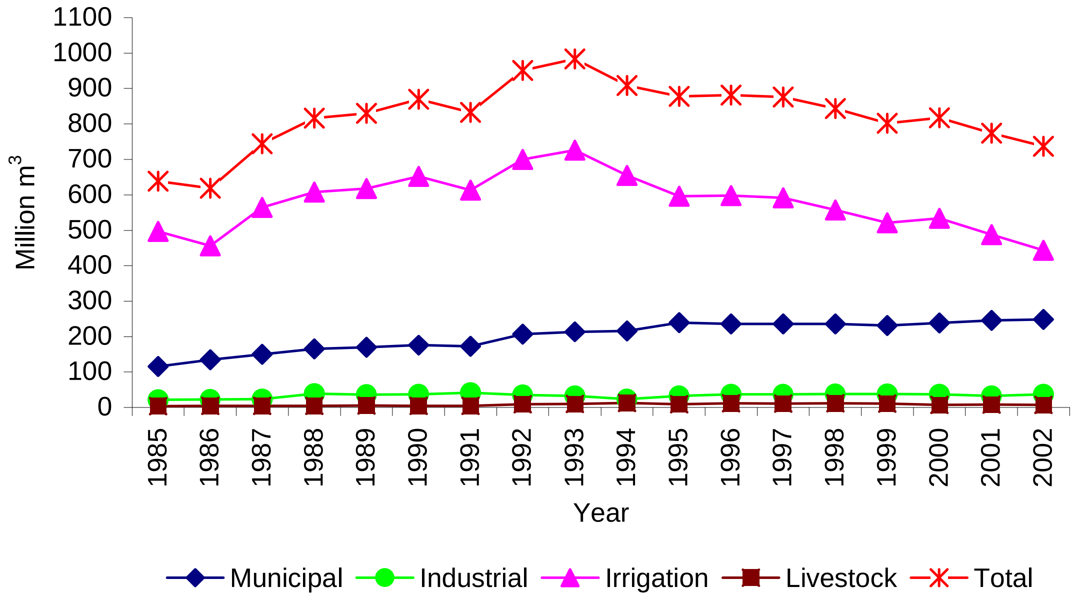


Figure 1.7: Water uses in Jordan 1985-2002 (Shatanawi et al., 2008)

1.2 Agriculture and irrigation practice in Jordan

The area under rain fed agriculture in Jordan during 1980-1991 comprised 230,000 hectares. This corresponds to 0.025 % of the total Jordan area. The main part of 140,000 hectares is the area planted with winter crops (wheat, barley, lentils, broad beans, and forages). Only about 16,000 hectares are planted with summer crops (chickpeas, sesame, corn, and tobacco) and vegetables (e.g. tomato, eggplant, squash, and cucumber). Another 70,000 hectares were planted with fruit trees and 10,000 hectares with forages (FAO, 2007). **Table 1.4** shows the area of crops grown in Jordan during 1995-2005 (FAO, 2007).

Table 1.4: Area of crops grown in Jordan during 1995-2005 [1000 ha] (FAO, 2007)

	1995	1996	1997	1998	1999	2000	2005
Field crops	150	121	161	172	184	116	121
Vegetables	42.9	27.2	30.3	7.4	35.7	32.9	40.2
Fruit trees	70.7	71.9	83.1	84.6	85.7	86.9	86.1
Total	**263.6**	**220.1**	**274.4**	**264**	**305.4**	**235.8**	**247.3**

Table 1.5 shows the land resources utilization of Jordan. 90% of the total land area is used as rangelands in the semi-desert regions. Out of this, 73% receive less than 50 mm of rainfall

annually and the remaining area less than 200 mm. Due to harsh environmental conditions, overgrazing and cultivation in the semi desert regions as well as an irregular and uneven distributed rainfall, these lands suffer from a general state of degradation. Therefore, irrigation is focused on this area with a total of 83,000 hectares in 2003. The irrigated area of the Jordan Valley and southern Ghor is about 30,000 hectares. The main source of irrigation water is the surface water (FAO, 2007).

Table 1.5: Land utilization in Jordan (FAO, 2007)

Utilization pattern	Area [million ha]	Total area [%]
Rangelands	8.07	90.4
Buildings and public utilities	0.17	1.9
Land used for forestry	0.07	0.8
Land registered as afforested	0.06	0.7
Water area	0.05	0.5
Agriculture land	0.51	5.7
Total	**8.93**	**100.0**

The cultivated land under irrigation increased more than twice within the last 14 years whereas the cultivated rain fed areas decreased as a result of urbanization. Moreover, a trend to cultivate more economical crops (olives, vegetables, and medicinal herbal plants), grown on a small scale, becomes evident (**Table 1.6**) (FAO, 2007). Eggplant is one of the main Jordanian summer vegetables that is well adapted to warm and hot climates. The Jordanian consumers generally like big eggplant fruits for the preparation of the popular appetizers (Arabic name: Baba ghanoush) whereas the smaller are preferred fruits for frying and cooking. The farmers also prefer to cultivate eggplants because it is easy to recover the cultivation cost as well as gained profits.

Table 1.6: Crop productions [1000 tons] (FAO, 2007)

Crop / year	2000	2001	2002	2003	2004
Wheat	25.4	19.3	44.0	42.5	13.2
Barley	12.1	17.3	56.0	25.8	21.0
Vegetables	966	844	1170	1137	1341
Summer vegetables	503	387	604	474	595
Winter vegetables	463	457	566	663	746
Olives	134	66	181	118	161
Grapes	24.0	58.0	35.0	28.0	32.0

1.3 Wastewater reuse in Jordan

As an alternative for fresh water use for irrigation purpose, treated wastewater has become important in water resources management. Using unconventional water resources, including industrial wastewater, might cause a negative environmental impact, which is intended to be solved by recycling and re-treating such resources (Kiziloglu et al., 2008; Kisku et al., 2000). Corresponding to the water shortage the reuse of reclaimed wastewater is an ever increasing international practice in irrigation, industry, and for recharge of groundwater (Kalavrouziotis and Apostolopoulos, 2007). The reuse of treated wastewater may contribute considerably to alleviate the pressure of using freshwater resources for irrigation. Wastewater treatment is one of the commercially most important processes in the world which is performed at largest technological scales. Since the 1980s, treated wastewater has been well known to be used for agriculture and considered as a fertile source of essential nutrients necessary for plant growth (Mohammad and Ayadi, 2004).

Wastewater represents an extremely complex mixture of organic and inorganic materials (Horan, 1993). Different wastewater qualities are used for agriculture (Lubello et al., 2004). Botti et al. (1998) reported that the high level of salinity in treated wastewater may negatively affect crop growth. In contrast, treated wastewater is considered as a rich source of plant nutrients, i.e., nitrogen, phosphorus, sulphur, and some metals such as calcium, magnesium and potassium, and micronutrients particularly iron, manganese and boron.

Particular attention needs to be paid when using waters for irrigation, which contain phytotoxic trace elements, e.g., Cr, Cd, Ni, etc. (Batarseh, 2006). Heavy metal pollution represents an important environmental problem due to the toxic effects of metals and their potential for accumulation within the food chain, which may lead to serious ecological and health problems. The main sources of heavy metal pollution are mining, milling, and surface finishing industries (Kim et al., 2007).

In addition to inorganic pollutants, wastewaters may contain a variety of microorganisms including bacteria, fungi, protozoa and nematodes (Williams and Baun, 2003). This enhances the risk of soil contamination by pathogens, in addition to heavy metals and persistent organic pollutants. Therefore, prior to the use of reclaimed water, its quality has to be checked for the biological, physical and chemical composition.

In Jordan, the water scarcity brought forth the use of large amounts of wastewater for irrigation purposes (Khleifat et al., 2006) with an increasing tendency (Al-Zboon and Al-Ananzeh, 2008). The wastewater production in Jordan was 75 and 90 million m^3 in 2003 and 2006, respectively, and expected to reach 200 million m^3 in 2020 (MWI, 2012a). The water strategy of Jordan emphasized that treated wastewater will constitute a substantial percentage of the irrigation water in future years (MWI, 2012b) and non-domestic purposes, including groundwater recharge (MWI, 2012c).

1.3.1 Standards and law

Water recycling is still perceived negatively in the public. It is considered to present risks to public health and to the environment. Therefore, the public confidence must be enhanced as well as the sustainable management of the recycled water. Moreover, practical framework of regulations and laws that helps to ensure public health and low environmental impact need to be established. A significant progress was made by the Jordanian government to optimize the reuse of wastewater resources (MWI, 2012c).

Historically, the first water law in the region was enacted by the Ottoman Sultan Abdul Hamid II (ruled 1876-1909) to provide the basis for the resolution of disputes over water and land ownership. This law survived in Jordan and it was incorporated in the 1952 Law of Water and Land Settlement. In Al Salt, 30 kilometers west of Amman, wastewater collection has practiced in Jordan in a limited way since 1930. For this, septic tanks and cesspits were used and grey water was often discharged to gardens resulting in environmental and public health problems. Since 1955, several laws for water regulations have been enacted. Municipality law number 29/1955, enacted in 1955, gave the government authorities of Amman the legal capacity to own and operate water systems and to specify standards for water system constructions. In 1966, law number 79/1966, empowered government agencies with the capacity to regulate the disposition, collection or discharging of wastewater that might cause a nuisance or damage. The public health framework was established by public health law number 21. Enacted in 1971 to control the wastewater, the law gave the Ministry of Health (MOH) the authority to monitor and regulate wastewater discharges and the design of wastewater facilities. The Jordan Valley Authority (JVA) was created by law number 18/1977. Under this law, the JVA has directed to develop wastewater systems in the valley and built an advanced water and wastewater management system. During the period from 1982 until 1989, a rather martial law (number 2/1982) was enacted. This law was specifically targeted to control discharges from industries into the natural water system, particularly in the Amman-Zarqa basin, where the majority of the population lives. Under law number 54/1992 the ministry of water and irrigation (MWI) was created in 1992 to consolidate the control over water resources and to achieve policy alignment. MWI gained substantial power to allocate and regulate the water resources of Jordan and to resolve differences among agricultural users, water supply authorities, wastewater treatment and reuse activities (Nazzal et al., 2000).

Due to the rapid growth of wastewater formation, it remains necessary for Jordan to expand the agricultural reuse of treated wastewater and to enhance recycling industrial water in the future. Most wastewater treatment plants in Jordan are designed to meet Jordanian Standard 893 with discharging to Wadis being the primary goal. This standard requires the BOD_5 reduction to 50 mg/L for the protection of aquatic environment. With a BOD_5 of 150 mg/L or more, the costs of treatment could be substantially reduced and the quality is still acceptable to farmers. Considering the Wadis discharge standard for total suspended solids, 50 mg/L may be too rigorous when there is no real threat to the aquatic environment. An ammonia discharge concentration (as nitrogen) of 15 mg/L to Wadis is difficult and expensive to achieve. Higher concentrations would have only small effects on health and the environment in most circumstances in Jordan where surface water is scarce (Nazzal et al., 2000).
The Jordanian standards currently forbid the use of treated wastewater for irrigation of vegetable crops that may be eaten raw like lettuce, tomatoes, and onions. However, wastewater treatment processes and treated wastewater quality and quantity improvement in Jordan are growing substantially. Thus, it may be beneficial for Jordan to expand the use of high-quality reclaimed water to cultivate high-value crops by maintaining a high standard of public health.
In addition, improved standards coupled with careful oversight of commercial companies could lead to a significant industry in the production of safe soil conditioners made from sludge. In the longer term, Jordan’s standards for wastewater treatment may be amended to achieve even greater flexibility to meet specific conditions of effluent reuse and to control the costs of treatment. Increasing the value of reclaimed wastewater and obligation to improve the use of this resource are underlined in Jordan’s wastewater management policy of 1998. The management concepts for wastewater treatment are increasingly driven by the need for optimal wastewater reuse. One of the next steps will be to improve standards and flexible decision-making processes that allow designers to shape the entire wastewater collection, conveyance, and treatment design around the anticipated reuse of wastewater (Nazzal et al., 2000). **Table 1.7** represents the standard biological, chemical, and physical properties of the reclaimed wastewater that are adopted by the Jordan Institution for Standards and Metrology (JISM). Wastewaters confirming the standard properties can be used for irrigation and put up for Seoul’s, Valleys, and water bodies (JISM, 2007).

Table 1.7: Biological, chemical, and physical properties of reclaimed wastewater, which allows their use for irrigation and put up for Seoul's, Valleys and water bodies (JISM, 2007)

Parameter	Water bodies [mg/L]	Irrigation [mg/L]
Biological oxygen demand (BOD_5)	60	30 [7], 200 [8]
Chemical oxygen demand (COD)	150	100 [7], 500 [8]
Disolved oxygen (DO)	≥ 2	NA
Total suspended solids (TSS)	60	NA
Alkalinity (pH [1])	6-9	6-9
Change in temperature of the receiving water, T [2]	6	NA
Color (C [3])	15	NA
Turbidity, NTU [4]	15	10
Escherichia coli [5]	1000	100 [7], 1000 [8]
Intestinal Helminthes Eggs [6]	≤ 1	≤ 1
Fat, oil and grease (FOG)	8	8
Surfactants, methylene blue active substances (MBAS)	25	100
Total disolved solids (TDS)	2000	2000
Total nitrogen	70	45 [7], 70 [8]
Sodium adsorption ratio (SAR)	9	9
Total organic carbon (TOC)	55	NA
Phenol	< 0.002	< 0.002
NO_3^-	80	30 [7], 45 [8]
PO_4^{3-}	15	30
SO_4^{2-}	300	500
NH_4^+	5	NA
HCO_3^-	400	400
Cl^-	350	400
CN^-	0.05	0.1
F^-	2	2
B	1	1
Al	2	5
As	0.05	0.1

[1] [Unit], [2] [^oC], [3] [Cobalt], [4] [Nephelometer], [5] Colony forming unit [(CFU)/100 mL], [6] [Egg/L], [7] For vegetables irrigation, [8] For fruit trees irrigation, NA: Not available

Table 1.7 : Continued

Parameter	Water bodies [mg/L]	Irrigation [mg/L]
Be	0.1	0.1
Cu	1.5	0.2
Fe	5	5
Li	2.5	0.075
Mn	0.2	0.2
Mo	0.01	0.01
Ni	0.2	0.2
Pb	0.2	0.2
Se	0.05	0.05
Cd	0.01	0.01
Zn	5	5
Cr	0.1	0.1
Hg	0.002	0.002
V	0.1	0.1
Co	0.05	0.05
Ag	0.1	0.1

1.3.2 Resources and quality

Wastewater in Jordan is characterized by very high salinity, ranged between 700-1200 mg/L, which primarily is caused by domestic drinking water with a TDS average value of about 580 mg/L (Ammary, 2007). Al-Zboon and Al-Ananzeh (2008) also mentioned that the wastewater in Jordan must be classified as a strong wastewater where the concentration of pollutants is much higher than the international reference values. The average concentrations of BOD_5, COD, TDS, and TSS for the influent wastewater are 880, 1946, 1000, and 795 mg/L, respectively. Which, is too high compared with the Iranian wastewater; the mean values of BOD_5, COD, and TSS were 242, 628 and 231 mg/L, respectively (Sarafaz et al., 2007).
Besides the high salinity wastewater in Jordan is characterized in general by insignificant concentrations of heavy metals and toxic organic compounds (Ammary, 2006). In some cases, it may be polluted by toxic heavy metals, e.g., Cd, Ni, Co, Zn, Pb, and persistent organic compounds, e.g., polycyclic aromatic hydrocarbons, polychlorinated biphenyls, pesticides, phenols, chlorinated benzenes (Jiries et al., 2000; Batarseh et al., 2003; Al Nasir

and Batarseh, 2008). Reclaimed wastewater irrigation may thus enhance the risk of soil salinization and soil pollution. Detailed values of untreated wastewater composition are summarized in **Table 1.8 and 1.9**.

As an example, all of the wastewater generated in the capital Amman is treated for reuse in the Jordan Valley. However, countrywide only 40% of the wastewater is collected and treated. The plan of the MWI is to increase the collection and to improve the treatment by establishing more treatment plants in different places in Jordan. Estimating that the sewerage service will increase from the current 50% to cover most of the townships and cities of the country by 2020, about 240 million m^3/y of wastewater are expected to be generated (MWI, 2012c).

The As-Samra plant near Al Zarqa city is the most important treatment plant in Jordan and is considered as one of the biggest in the world serving about half the population of the country (JICA, 2001). The Jordan strategy emphasizes to rehabilitate and expand its wastewater treatment plants and exploring options for smaller communities (Scott et al., 2004). It is expected that the Jordan population will reach about 10 million inhabitants by the year of 2025. By this, the percentage of the population with sewerage services will increase, and about 280 million m^3/y of wastewater is expected to be generated.

Table 1.8: Average influent wastewater characteristics of 19 wastewater treatment plants in Jordan in 1998 (Ammary, 2007)

Wastewater treatment plant	BOD_5	COD	TSS	NH_4^+	TDS
Abu Nuseir	552	1225	558	40	1060
Aqaba	373	789	338	61	782
As-Samra	708	1789	556	85	1153
Baqa	1027	2166	991	94	1154
Fuhais	750	981	612	95	789
Irbid	1173	2670	1136	114	NA
Jarash	1231	2171	756	68	1239
Karak	697	1639	561	64	1050
Kufranja	1186	1992	885	76	1344
Ma’an	518	890	337	118	730
Madaba	1048	2422	652	128	1896
Mafraq	683	1171	1132	140	1106
Ramtha	849	1481	733	165	1240
Salt	868	1519	864	120	860
Tafielah	630	1517	574	70	760
Wadi Essir	431	670	320	80	1205
Wadi Arab	653	1182	758	35	NA
Wadi Hassan	977	2162	915	130	1100
Wadi Mousa	608	988	587	65	981

NA: Not available

Table 1.9: Influent and effluent wastewater characteristics in four big plants in Jordan (Al-Zboon and Al-Ananzeh, 2008)

		Al-Samra	Irbid	Ramtha	Wadi Hassan	Average
BOD_5 [mg/L]	Influent	705	1030	915	870	880
	effluent	140	32	13	12	49
	removal %	80	97	98	98	93
COD [mg/L]	Influent	1890	2205	1980	1710	1946
	effluent	605	110	70	63	212
	removal %	68	95	96	96	89
TSS [mg/L]	Influent	591	1040	780	770	795
	effluent	117	51	30	25	56
	removal %	80	95	96	97	92
NH_4-N [mg/L]	Influent	90	108	90	118	102
	effluent	97	12	1	4	28
	removal %	*	88	99	97	95
DO [mg/L]	effluent	1.8	3.9	4.3	5.8	4.0

* Effluent concentration higher than influent concentration.

BOD: Biological oxygen demand, COD: Chemical oxygen demand, TSS: Total suspended solids, DO: Dissolved oxygen.

1.4 Soil amendments

Dry lands degradation or desertification is caused by the loss of biological productivity and complexity that mainly refers to climate variability and unsustainable human activities like overcultivation, overgrazing, deforestation, and poor irrigation practices (Hüttermann et al., 2009). Soil amendment compounds and fertilizers are materials added to soil to improve its physical properties, i.e., water retention, permeability, water infiltration, drainage, aeration, and structure. By this, a better environment for roots in addition to the plant growth is provided (Davis and Wilson, 2005). Soil amendments are mixed mainly into the topsoil to promote healthy plant growth by moderating the pH of soil and as nutrient supply. Soil conditioners, like composted manure and humic compounds, can help to improve the soil structure by increasing the amount of pore space and enhancing the air exchange, water movement, and root growth. In addition, nutrients like nitrogen (N), phosphorus (P), and potassium (K) are the main chemicals that must be supplied to plants in adequate amounts. The secondary nutrients like calcium, magnesium, and sulfur are also required by plants as well as very small amounts of the micronutrients boron, copper, chlorine, iron, manganese, molybdenum, and zinc. Most plants grow better in soils containing organic matter higher than 3% (w/w) and pH 5.5-7 in the topsoil.

Sandy soil, which represents 90% of the Jordan total area, is the most porous, poorest and the lightest of all soil textures. Therefore, it is not suitable for plants requiring high soil moisture for growth. In general, its lacking of nutrients makes it very poor growing medium on its own. To improve the water retention and the needed nutrients to sustain plant life, sandy soils must be amended. An advantage over the other soil textures is its ability to warm up quickly in the spring, allowing for an earlier planting date.

There are two categories of soil amendments: organic and inorganic materials. Organic amendments are derived from natural or living organism’s sources. Inorganic amendments are either mined or produced by the industry. Besides increasing the organic matter content in soils, organic amendments improve the soil aeration, water infiltration, and water holding capacity. Many organic amendments contain plant nutrients that act as organic fertilizers and are also energy sources for bacteria, fungi, and earthworms that live in the soil. The permeability and water retention of different soil textures and soil amendments are presented in **Tables 1.10 and 1.11** (Davis and Wilson, 2005).

Some commercial soil conditioners are mentioned in **Table 1.12** (Maryland cooperative extension, 2009). In the literatures, biochar and superabsorbent polymers are the most interesting soil amendments under study worldwide for scientist these days, especially to enhance the water holding capacity of the soil. Therefore, the uses and limitations of biochar and superabsorbent polymers as soil amendments were discussed in the next sections.

Table 1.10: Permeability and water retention of various soil amendments (Davis and Wilson, 2005)

Amendment	Permeability	Water Retention
Fibrous		
Peat	low - medium	very high
Wood chips	high	low - medium
Hardwood bark	high	low - medium
Humus		
Compos	low - medium	medium - high
Aged manure	low - medium	medium
Inorganic		
Vermiculite	high	high
Perlite	high	low

Table 1.11: Permeability and water retention of various soil textures (Davis and Wilson, 2005)

Soil Texture	Permeability	Water Retention
Sand	high	low
Loam	medium	medium
Silt	low	high
Clay	low	high

Table 1.12: Different kinds of commercial soil conditioners

Soil conditioners	Notes
Sul-Po-Mag	Sulfate of potash magnesia from the mineral langbeinite, with about 22% sulfur, 22% potash and 18% magnesium oxide
Urea	Rapid nitrogen release with a high burn potential.
Wood ashes	1 to 2% phosphorus and from 4 to 10% potassium
Worm castings	The rich digested “soil” produced by redworm farming
Compost commercial or home-grown	Made from decayed organic materials such as straw, corn cobs, food wastes, cocoa bean hulls, poultry litter, grass clippings, leaves, manure
Gypsum	Calcium sulfate, a mined product also called “land plaster”. Can be used on very heavy, clay soils to improve soil structure without raising soil pH
Humus	The stable end product of the composting process
Humic acid	An important component of organic matter
LeafGro	Composted leaves and yard debris
Mushroom compost	Compost from mushroom farming. It is some combination of manures, wheat straw, corn cobs, feathermeal, etc.
Peat moss	Partially composted moss mined from prehistoric non-renewable bogs. Light, porous, absorbs 20 times its weight in water
Pine bark fines	A finely shredded pine bark product that retains moisture.
Sand	To improve water drainage and aeration of clay soils a minimum of 50% by volume is necessary
Sawdust	Only well-decayed sawdust should be incorporated into the soil
Water-absorbing polymers (hydrogels)	Granules that can absorb 300-400 times their weight in water. As soil dries, stored water is released slowly back into soil. Also absorbs and releases fertilizer.

1.4.1 Biochar

Biochar is a relatively new term but not a new substance. Soils throughout the world naturally contain charcoal through forest and grassland fires (Hunt et al., 2010). It is created by heating organic material under limited or no oxygen conditions (Lehmann, 2007). Its residence times in soils can be manipulated to design the best possible biochar for a given soil type (Steinbeiss et al., 2009).

Biochar can be used for contaminated land remediation because it was effective to decrease concentrations of Cd in pore water by the factor 10 and to reduce of polycyclic aromatic hydrocarbons (PAHs) by 50% (Beesley et al., 2010). PAHs can be created by incomplete burning processes of coal, oil, gas, and garbage carbon-based fuels (Preston and Schmidt, 2006) and exist in over 100 different combinations (EPA, 2008). Biochar has become more and more important as soil conditioner to avoid leaching of nutrients, to increase microbial biomass and activity, to remediate the soil of organic pollutants, etc. The total PAHs concentrations in about 40 commercial biochar products were investigated by Hilber et al. (2012). The results showed that the total concentrations of PAHs in the biochars ranged from 0.4 to 355 mg Σ16 EPA PAH/kg biochar. The International Biochar Initiative guideline set the maximum allowed threshold value at 6 mg Σ16 EPA PAH/kg biochar. Thus, biochar applications might become a problem, especially for legislation accounting for total concentrations.

The high capacity of adsorption, cation exchange, and low levels of mobile matter, i.e., tars and resins are the most important measures of biochar quality (McClellan et al., 2007). McElligott (2011) found that the biomass production of poplar trees grown in a fine-textured and coarse-textured forest Andisol amended with 25% and 50% (v/v) hardwood mill waste biochar for eight weeks, varied by soil type. But, the biochar treatments had no effect on biomass in either soil. There was no significant trend between decreasing biomass and increasing biochar ratio in the fine and coarse Andisol. However, the biomass increased significantly when biochar combined with the complete fertilizers relative to unfertilized. The biochar had a neutral effect on poplar trees growth and could be returned to forest soils to replenish soil nutrient stocks and enhance carbon storage, but with little to no effect on tree growth in the short-term. Conversely, Hoshi (2001) recorded that 20% and 40% increase in tea plants (*Camellia sinensis var. sinensis*) volume and height with biochar additions, respectively. Chidumayo (1994) reported that the seed germination, shoot heights, and biomass production among native woody plants on soils is better under charcoal kilns if compared to plants growth on undisturbed Zambian Alfisols and Ultisols. Even in the absence of nitrogen fertilizer, applications of biochar as a soil amendment increase significantly the crop yields. The application of nitrogen fertilizer increase the crop yields significantly in both biochar treatments (biochar-A, pyrolyzed from corn cobs at 450 ^{o}C and biochar-B, produced from wood chips at 450 ^{o}C). When the use of biochar was integrated with fertilizer, the crop yield increased by approximately 54% and 39% for biochar-A and biochar-B in the 50% fertilizer treatment, respectively, and 72% and 44% in 100% fertilizer use, respectively (**Figure 1.9**) as well as for the soil quality, i.e., organic matter, pH, cation exchange capacity, and holding nutrients was improved when biochar used as soil amendment (**Table 1.13**) (Zheng et al., 2010). Water holding capacity (WHC) in sandy soils was improved by biochar application. The WHC of the loamy sand soil was improved with 349-481% compared to 36-56% for sandy loam soil and 27-41% for silt loam soil after application of maize stover biochar at three ratios 5, 10 and 15 t/ha. Even though significant difference was found between the zero biochar and other biochar ratios, no significant difference was reported between 5, 10 and 15 t/ha, suggesting that the optimum ratio of bio-char application to improve soil moisture retention is 5 t/ha (Dugan et al., 2010).

McClellan et al. (2007) demonstrated the effectiveness of charcoal additions on lettuce plant growth in two Hawaiian soils amended with four charcoal percentages 0, 5, 10 and 20% (w/w). They found the shoot biomass and the nitrogen uptakes were significantly decreased by increasing of charcoal ratio and significant increase for the soil nitrogen content and soil carbon source. Chan et al. (2007) investigated the effect of application of biochar originate from the green wastes in the presence and absence of nitrogen fertilizers on the radish dry matter. The biochar did not affect the radish dry matter in the absence of nitrogen fertilizers and the significant increase effects appear only in the presence of nitrogen fertilizers (**Figure 1.10**). Changes in soil physical, chemical, and biological properties were investigated by Chan et al. (2007). The field capacity, pH, organic carbon, exchangeable Na, K and Ca, extractable P and the soil biological activity were increased proportionally with increasing biochar application ratio. The significant changes were observed only at higher biochar application amounts 50 and 100 t/ha especially in the presence of nitrogen fertilizers. The pH and field capacity increased from 4.77 and 2.55 g/kg at the control to 5.99 and 3.2 g/kg at 100 t/ha, respectively.

Table 1.13: Effect of biochar and fertilizers amendments on the soil properties (Zheng et al., 2010)

Treatments		Organic Matter [%]	P [mg/kg]	K [mg/kg]	pH	Cation Exchange Capacity [meq/100g]	N [mg/kg]
No fertilizer	No biochar	3.9	30	198	5.4	15.2	21
	Biochar-A	5.0	46	259	6.1	16.1	12
	Biochar-B	4.5	31	166	5.8	20.1	21
50% fertilizer	No biochar	4.5	38	176	5.5	18.3	32
	Biochar-A	5.5	74	342	6.2	19.0	29
	Biochar-B	4.8	47	179	6.1	21.3	25
100% fertilizer	No biochar	4.2	21	175	5.8	17.7	58
	Biochar-A	5.1	60	239	6.5	22.6	13
	Biochar-B	4.9	39	221	5.9	20.9	56

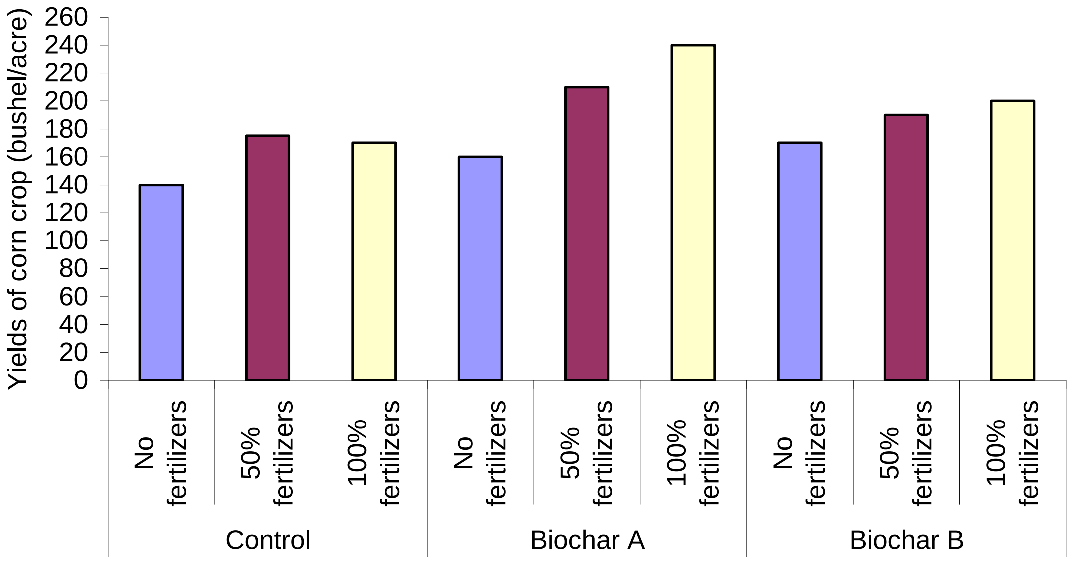


Figure 1.9: Effect of biochar on corn yields under different nitrogen fertilizer application rates (Zheng et al., 2010).

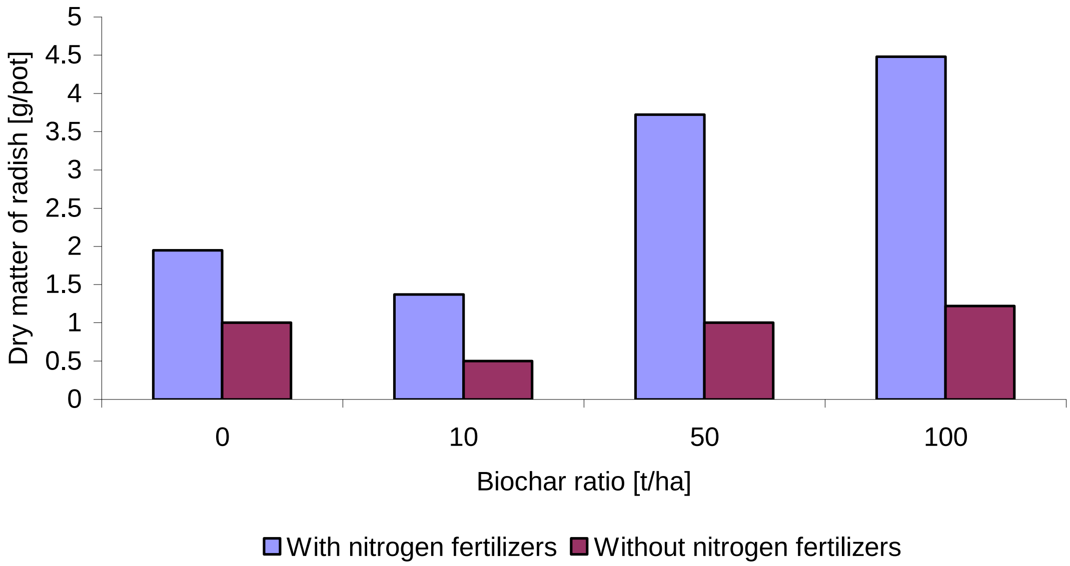


Figure 1.10: Dry matter production of radish with and without nitrogen fertilizers (Chan et al., 2007)

The type and source of used organic matter and the production conditions, greatly affect the quality of biochar as a soil amendment (McClellan et al., 2007). Soil improvement was depending on the source of biochar. The composition of biochar varies by feedstock type and conditions of pyrolysis. The actual carbon contents ranged between 172-905 g/kg, nitrogen 1.8-56.4 g/kg, phosphorus 2.7-480 g/kg and total potassium 1-58 g/kg (Chan et al., 2007). Other elements, i.e., oxygen, hydrogen, nitrogen, sulfur, phosphorus, base cations, and heavy metals are found within the biochar in varying concentrations (McElligott, 2011). High volatile matter content charcoal has a detrimental effect on plant growth but the low volatile matter charcoal may have a beneficial effect on plant growth, especially when combined with fertilizer (McClellan et al., 2007).

Biochar from different feedstock such as switchgrass, digester fiber, woody and activated charcoal were amended to 5 different Washington State soils. The effect of biochar was pH increase, no consistent plant growth improvement, increase the soil carbon content, persistent biochar carbon estimated to hundreds of years (Granatstein et al., 2009). The physical structures of biochar had a huge variability depending on the parent material and the conditions present at their formation, leading to quite differences in soil amendment. Large particles of biochar originated from forest wildfires have ability to remain in soils for thousands of years. However, smaller particles that derived from grassland burning can hardly be detected in ecosystems. The physical and chemical structure, i.e., surface area, condensation grade, and the particle size of synthetic biochars can be modified in technical processes and opening the question about the stability of synthetic biochars in soils (Steinbeiss et al., 2009).

Data on the effect of charcoal on crop yields is still not enough, only a limited number of crops grown and investigated in a limited number of soils. The interactions between crop, soil type, local conditions, and biochar feedstock, production method, and application rate need to be studied in far more detail before large scale deployment of biochar as a soil amendment. Nonetheless, there is evidence that the addition of charcoal may be beneficial to some crop-soil combinations.

In spite of some expected benefits of using biochar as soil amendments, there are limitations of using this material. The strong bonds between carbon atoms in charcoal makes biochar resistant to attack and decomposition by microorganisms (Shackley et al., 2009). The half-life of biochar found to be 6623 years in coastal temperate forests (Lehmann and Joseph, 2012). Biochar may contain dioxins and poly-aromatic hydrocarbons (PAH) as result of pyrolysis, therefore, negative impacts arising from applying biochar to the soil (Shackley et al., 2009). From the above mentioned biochar characteristics, this material is not degradable, persistent in nature for long time, and this material contaminated on its own with PAHs and dioxins. Therefore, this material was not within the interest to be carried out within this study.

1.4.2 Superabsorbent polymers

The use of superabsorbent polymers (hydrogels) in agricultural soil amendment was developed by the United States Department of Agriculture (USDA) in the 1970s. At the beginning it was applied to improve the soils water holding capacity and plant growth. Based on its high absorbency it became useful for many additional applications (Liu and Guo, 2001). Superabsorbent polymers are commonly sold at horticultural markets as water super-absorbers with absorbing capabilities of 400-1500 g water per dry gram of hydrogel (Bowman and Evans, 1991; Akhter et al., 2004).

Superabsorbent polymers are a special type of polymers with highly cross-linkages, high molecular weight, and it is mostly synthesized using acrylamide, acrylate or acrylic acid (Hüttermann et al., 2009). Superabsorbent polymer contains high amounts of functional groups enabling them to absorb large amounts of liquid and retain it (John, 2011). With increasing cross-linkage of the polymer chains the swelling decreases (Liu and Guo, 2001). Cross-linking makes superabsorbent polymers insoluble in water (John, 2011). Water absorption of superabsorbent polymers is affected by morphological properties like porosity (Kabiri and Zohuriaan-Mehr, 2004), grain size (John, 2011), and environmental conditions such as temperature, pH and ionic strength (Liu et al., 1995). The schematic of the SAP swelling is presented in **Figure 1.10** (Zohuriaan-Mehr and Kabiri, 2008).

Peterson (2009) mentioned that hundreds of types of hydrogels exist and the term hydrogel itself is rather generic. Hydrogels are classified into three classes. The first class is the natural starch based polymers. They are commonly derived from grain crops such as corn and wheat and commonly used in the food industry. A second class is semi-synthetic SAPs. They are initially derived from cellulose and then combined with forms of petrochemicals, which are usually altered cationically or anionically. Third class is the synthetic polymers, they are chemically crosslinked to prevent them from dissolving in and considered as the main type used for horticultural purposes. They usually consist of polyvinylalcohols and polyacrylamides. The polymers’ effectiveness depends on their chemical formula and on the purpose of use (Mikkelsen, 1994). There are many applications for the hydrogels in oil recovery (Tongwa et al., 1999), for medical purposes (Nicholas et al., 2006), in agriculture (Hüttermann et al., 1997, 1999, 2009), in wastewater treatment (Wang et al., 2008), and in diapers (Zohuriaan-Mehr et al., 2008).

Hüttermann et al. (2009) mentioned a variety of different polymers, which were developed some decades after the 1950s and tested for the design of this special type of soil conditioner, which included guar, starch, polyacrylate and poly(ethylene glycol), alginate-poly(sodium acrylate-coacrylamide), carboxymethylchitosan-g-poly(acrylic acid) copolymer, polyacrylamide, polyacrylamide/sodium alginate, polyacrylic acid, etc. Commercially, the most important SAPs at present are:

- Aqualic^{TM}, a cross-linked copolymer of sodium acrylate and acrylic acid, produced by Nippon Shokubai, Osaka, Japan;
- Luquasorb^{TM}, a cross-linked copolymer of potassium acrylate and acrylic acid, produced by BASF SE, Ludwigshafen, Germany (**Figure 1.11**) and
- Stockosorb^{TM}, a cross-linked polymer of acrylamide and sodium/potassium acrylate, produced by Creavis, Krefeld, Germany (Hüttermann et al., 2009).

SAPs are similar to artificial humus as they are hydrophilic and contain carboxylic groups. Both SAP and humus in soil have a similar structure as well as functional groups, which are hydrophilic and bind cations. However, SAP has a much higher density of hydrophilic and cation binding groups and have no aromatic moieties leading to be much more effective per weight than humic substances. There is no possibility that they might become hydrophobic, as humus does under drought conditions (Hüttermann et al., 2009).

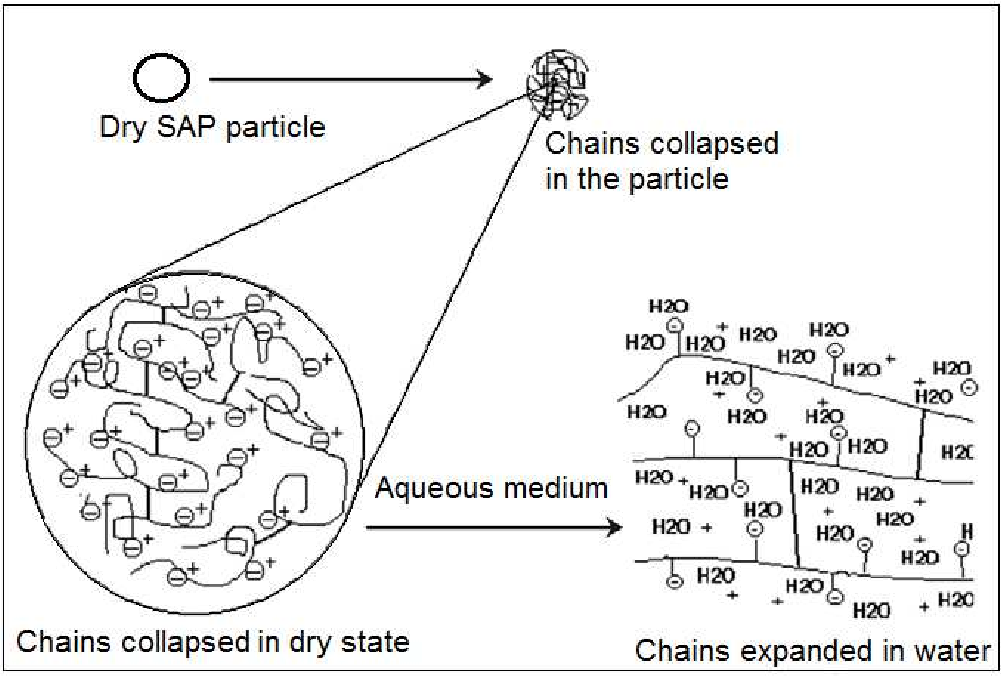


Figure 1.10: Scheme of an acrylic-based anionic superabsorbent hydrogel in swelling state (Zohuriaan-Mehr and Kabiri, 2008).

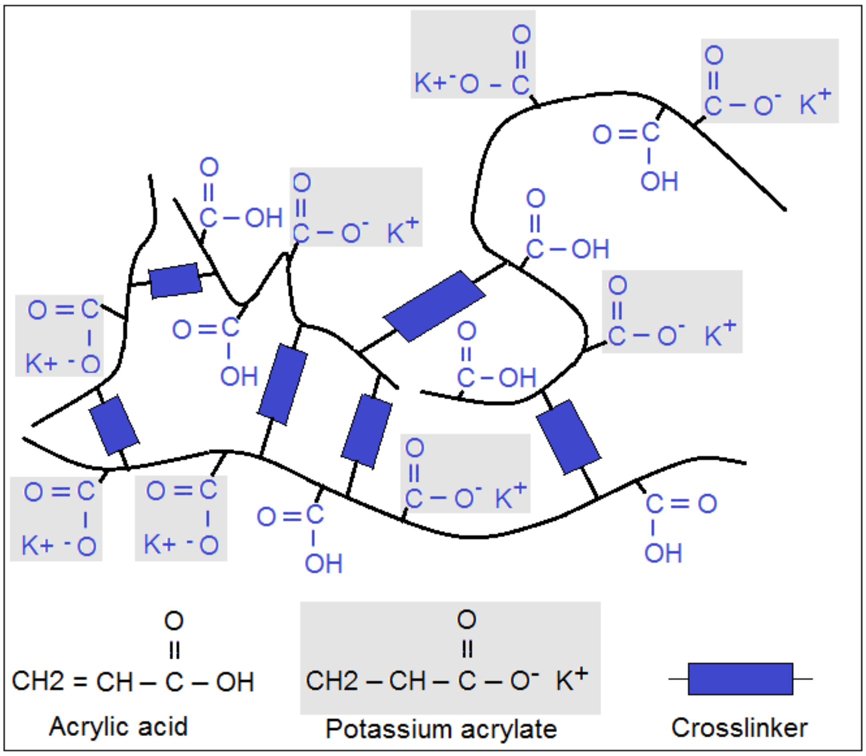


Figure 1.11: Formula of a cross-linked copolymer of potassium acrylate and acrylic acid (Luquasorb) (Hüttermann et al., 2009)

1.4.2.1 Uses of superabsorbent polymers in agriculture

Polymers have been known as soil conditioners since the 1950s (Hedrick and Mowry, 1952). These polymers were developed to improve the physical properties of poorly structured soils in areas subject to drought. The properties are of growing interest in view of increasing the water-holding capacity of soils, increasing water use efficiency, enhancing soil permeability and infiltration rates, reducing irrigation frequency, reducing compaction tendency, stopping erosion and water run-off, and increasing plant growth (Ekebafe et al., 2011; William and Gary, 1990). Influence the density, structure, compaction, texture, aggregate stability and crust hardness of the soil as well as the evaporation rates and microbial activity (John, 2011). The usual goal of adding hydrophilic polymer to the soil matrix is to enhance water holding capacity. The addition of hydrophilic polymer to a sandy soil changed the water holding capacity to be comparable to loamy soils (Hüttermann et al., 1999) and used to aid plant establishment and growth in dry soils (Zeineldin and Aldakheel, 2006). Agricultural polymers were also developed to improve the physical properties of soil (Jhurry, 1997). Tree species with less drought tolerance had more favorable response to the incorporation of hydrophilic polymers (Specht and Harvey-Jones, 2000). Orikiriza et al. (2009) found that an amendment of 0.2 and 0.4% polymer amount increased the biomass of nine tree species in sandy soil. The weight of roots, stems, leaves, and twigs were significantly higher than the control. For example, the biomass results of three of the nine species are presented in **Table 1.14.**

The agricultural production is limited in Jordan because of the low precipitation and high evapotranspiration. Therefore, SAP application in arid climates gained an importance within the research activities (Hüttermann et al., 2009; Agaba et al., 2010). The water loss due to drainage within sandy soils could be avoided by mixing the soil with a hydrophilic polymers (Buchholz and Graham, 1998). SAP application to the soil reduces infiltration and thus avoids potential loss by deep percolation (John, 2011; Hüttermann et al., 2009). The additional potential advantage of hydrogel application is to influence compaction, density and soil structure (Peterson, 2009), and evaporation rates (Al-Humaid and Moftah, 2007). The pH, total microbial count, and the high affinity to reduce the heavy metal and salt stress of crops were also influenced by the polymer ratio (**Table 1.15**). The plant roots are able to grow directly within the swollen hydrogel. Therefore, the absorbed water is available for the plant (Hüttermann et al., 1999). Superabsorbent polymers were applied and successfully reduced the water stress in the following plant species: Citrus, corn, poplar, barley, wheat, chick pea, *Eucalyptus*, pine, *Acacia melanoxylon*, lettuce, *Platycladis orientalis*, *Pinus tabulaeformis*, *Chlorophytum comosum*, pea, tomato, soy bean, etc. (Hüttermann et al., 2009).

Table 1.14: Growth of three tree species potted in sandy soil and amended with different hydrogel application rates. The different superscript letters in the same column are significantly different (Orikiriza et al., 2009)

Plant species and hydrogel ratio	Biomass (oven dry matter) Root	Stem	Leaves and twigs
Eucalyptus grandis			
Control	2.13^{c}	0.51^{c}	2.88^{c}
0.2 %	2.34^{b}	1.16^{b}	5.82^{b}
0.4 %	2.84^{a}	1.29^{a}	6.56^{a}
Eucalyptus citriodora			
Control	1.12^{c}	0.40^{c}	3.06^{c}
0.2 %	1.25^{b}	0.43^{b}	4.00^{b}
0.4 %	2.96^{a}	0.60^{a}	12.2^{a}
Pinus caribaea			
Control	1.30^{b}	0.15^{b}	1.28^{c}
0.2 %	1.92^{a}	0.16^{a}	1.38^{b}
0.4 %	1.99^{a}	0.17^{a}	1.68^{a}

The amendments of SAP contribute to delay permanent wilting points and to reduce drought stress on plants (Bhardwaj et al., 2007) leading to better seed germination, higher survival rates, and increasing growth under drought conditions (Akhter et al., 2004; Orikiriza et al., 2009). As an example, a delay in wilting point of wheat seedlings by 5-8 days was observed by Shahid et al. 2012 in the soil amended with polymer. Thereby, improving wheat plant growth and establishment, also the water retention of the sandy loam soil was increased up to 60 and 100% of field capacity with the application of 0.1 and 0.4% (w/w) of the polymer, respectively. Guiwei et al. (2008) mentioned that the application of 0.2% polymer ratio (w/w) increased the water-holding capacity to about twice value of the maximum water-holding capacity of the unamended soil that was about 250 g/kg. Moreover, the accumulated biomass of Orchard grass plants (*Dactylis glomerata* L. cv. Amba) over the four cuts was obtained in plants grown in soil with 0.4% polymer, which was more than 3000 times more than biomass of plants from soil with no polymer.

The cost of SAP amendment can be recovered by increase in production of crops, decrease in irrigation rate, and increase in plant survival rate. A kilogram of SAPs costs between 2 and 4 USD. Thus, the maximum price per hectare would be about 250 USD (Hüttermann et al., 2009).

Hüttermann et al. (1997, 1999) mentioned that the superabsorbent polymers (SAPs) could protect plants against water, salt, acidity, and heavy metal stress. The pH and total microbial count (**Table 1.15**). So, a combination between SAP amendment and reclaimed water irrigation may mitigate the possible negative impacts of wastewater reuse on soil productivity and plant growth (Hüttermann et al., 1997).

Table 1.15: Effect of the polyacrylate polymer application amount on soil pH, number of culturable bacteria and fungi (Hüttermann et al., 1997)

Polymer application amount % (w/w)	pH	Bacteria [CFU*.10^5/g]	Fungi [CFU*.10^5/g]
0.0	3.8	7	2
0.2	4.0	67	19
0.4	4.3	70	9
0.6	6.0	250	7

* CFU: Colony forming units

1.4.2.2 Limitations of superabsorbent polymers in agriculture

There are different limitations of superabsorbent polymers in agriculture. Variations in the effects of hydrophilic polymers and plant responses seem to be a result of the differences in the type of hydrophilic polymers, plant types, and soils (Akhter et al., 2004). In addition, the relative effectiveness of the hydrophilic polymers depends upon their chemical properties such as molecular weight (Abedi-Koupai and Asadkazemi, 2006). Conflicting results in hydrogel absorbency may be due to free ions in irrigation water or to the hydrogel type. Gel absorbency was reduced in aqueous salt solutions (Okay and Sariisik, 1999). Due to the nature and concentration of dissolved salts in irrigation waters, the water absorbing properties of the 3 main chemical families of hydrogels (acrylate copolymers, polyvinylalcohol copolymers, and polyacrylamide copolymers) are influenced differently (Johnson, 1984).

Changes of soil properties can be permanent or temporary, depending on the purpose used for (Peterson, 2009). Biodegradation of acrylic polymers is slow, the half life being from 5 to 7 years (Davies et al., 2004; Ekebafe et al., 2011; Abu Jaber, 2012). Two superabsorbent polymers in soil, a crosslinked polyacrylate and a polyacrylate/polyacrylamide copolymer, were degraded (solubilized and mineralized) by the white-rot fungus *Phanerochaete chrysosporium* (Sutherland et al., 1997). Stahl et al. (2000) recorded that cooperation between *P. chrysosporium* and soil microbes were found in the degradation of both the polyacrylate/polyacrylamide copolymer and polyacrylate in soil. The minimal mineralization of the copolymer was 0.35% in 76 days in the microcosms that did not contain the fungus while it was 4.3% in 76 days in microcosms containing sterilized soil incubated with inoculated sawdust and the highest mineralization was 7.3% in 76 days observed in microcosms containing inoculated sawdust and non-sterilized soil. Wolter et al. (2002) found out that after 22 weeks 9% of the initial radioactivity of ^{14}C-labeled acrylamide-acrylic acid was mineralized in soil that was inoculated with the white rot fungus *Pleurotus ostreatus.* The rates of decomposition of the radio-labeled crosslinked polyacrylates were in the range of 1-9% per year. This is similar to the decomposition rate of organic matter which is observed in forest ecosystems (Hüttermann et al., 2009). As examples, the decomposition rate of fresh plant litter in Scandinavian forest soils was 0.00001-0.1% per day (Berg, 2000); the weed biomass degradation in a coffee plantation on Sumatra reached values of between 7-14% after the first 4 years (Watanabe et al., 2007), and the lignin moiety of needles was degraded by 13% after 2 years in a Swedish forest (Sjöberg, 2004).

The polymers do not exhibit any ecotoxicity in the environment, but bacteria are unable to degrade these polymers because of the stability of the carbon-carbon backbone of polyacrylate polymers, their low solubility, and high molecular mass due to the cross linking. The high persistence of SAPs in soils may lead to increasing pollution concerns in the future (Stahl et al., 2000).

As mentioned above, the water holding capacity and available water content as well as the yield and water use efficiency of plants increased with the application of SAPs to the soil (Dorraji et al., 2010). On contrast, Kim and Nadarajah (2008) reported, SAPs can also dehydrate rapidly within nearly a week losing their absorbed water. The water absorption by SAPs also decreases by increase of water salinity (Lentz and Sojka, 2009) due to the formation of additional crosslinks with certain ions like Ca^{2+} and Al^{3+} present in the soil (Chatzoudis and Rigas, 1998). With increasing temperatures, SAP releases water (Andry et al., 2009), and by this, the efficiency of the SAPs decreases faster per time. To compensate for these losses, higher application rates are needed (Al-Harbi et al., 1999). In addition, Frantz et al. (2005) point out that SAP amendment may realize potential benefits in early stages of plant production and little or no benefit later in production and in post-production.

2. Motivation and objectives

The ability of superabsorbent polymers (SAPs) to absorb large volumes of water and to retain it has many practical applications in agriculture. Therefore, SAPs were used to improve the soil quality, increase soil water holding capacity and plant available water, reduce heavy metal and salt stress for plants, increase microbial activity in soil and increase the plant growth and crop yield. Furthermore, the availability in market and the cheep price of SAPs, 1 kg of SAP costs between 2 and 4 USD gave more encouragement to study the effect of these polymers to improve the Jordanian sandy soil quality.
On the one hand, desert areas represent more than 90% of the Jordan total area. Sandy soil is the most porous, poorest and the lightest of all soil types, in general, its lacking of nutrients makes it very poor growing medium on its own. In order to improve the water retention and the needed nutrients to sustain plant life, sandy soils must be amended. For these reasons, SAP Luquasorb hydrogel (manufactured by BASF SE, Chemical Company, Ludwigshafen, Germany) was chosen to be tested as soil amendments in Jordanian sandy soil. On the other hand, scarcity of water resources in Jordan and the vulnerability of soil and plants, which is known as desertification, are main driving forces for Jordanians to look for non-conventional water resources. Nowadays, Jordan tends to focus on using treated wastewater for agricultural purposes to replace third amount of fresh water which is used for irrigation purposes. However, treated wastewater may be a complex mixture of organic and inorganic materials as well as variety of microorganisms including bacteria, fungi, protozoa, and nematodes. For that reason, more attention has to be paid for treated wastewater reuse as alternative water resource for irrigation purposes. So far, SAPs have not been used for watering of plantations with treated wastewater. Therefore, this technique should be tested at test plot scale in Jordan for the use of fresh water and treated wastewater in eggplant cultivation.

The objective of this study was to investigate the impact of soil amended with super absorbent polymers on the irrigation efficiency and the usage of treated wastewater for irrigation purposes in sandy soil. Therefore, the possible environmental effects, which may result from the addition of this polymer to the soil and also the impact of treated wastewater for irrigation purposes on plant and soil quality, should be studied under field and laboratory conditions. To achieve this goal, eggplants should be cultivated in sandy soil amended with different concentrations of potassium polyacrylate superabsorbent polymer, i.e., 0.2% and 0.4%, and irrigated with different irrigation water qualities.

The field study should be carried out in order to investigate the effects of different concentrations of SAP on the water holding capacity and plant available water of Jordanian sandy soil irrigated with fresh water and treated wastewater. The growth parameters (stem diameter, plant height, and fruit yield) and the biomass of the cultivated eggplants in sandy soil amended with different concentrations of SAP and irrigated with different irrigation water qualities, should be recorded during the vegetation period. The ability of SAP amendments to mitigate the effect of high concentrations of salt and heavy metal in the irrigation water on eggplants also should be checked. At the end of vegetation period, the eggplants should be harvested. The water, soil and plant samples should be additionally collected for element analysis.

The laboratory studies should be carried out in order to investigate the sorption capacity and equilibrium exemplarily for cadmium in the Jordanian sandy soil with and without SAP application. The total organic carbon and total Kjeldahl nitrogen content as well as the soil respiration should be measured in control and soil samples that amended with different concentrations of SAP. Additionally, the effect of SAP application and irrigation water quality on the survival time, wilting point and the ability of plant to accumulate heavy metals as well as the total bacterial count and endophytic bacteria, should be investigated. Moreover, SAP degradability should be checked using the local bacterial isolates, which isolated from the field site. Furthermore, the ability of the bacterial isolates from the field site to accumulate cadmium by uptake and adsorption should be studied.

3. Materials and methods

3.1 Field location

The experimental field is located in Jordan, Al Karak Governorate, at Mutah University campus (altitude: 31°2′0″N 35°41′0″E, elevation: 820 m) near the wastewater treatment plant (**Figure 3.1**). Al-Karak region is characterized by cool wet winters and hot dry summers, with generally very short springs and autumns. Rainfall and temperature in the governorate are highly influenced by the altitude. At Mutah University, the annual rainfall averages about 350 mm and the annual mean temperatures range from 15.5-17 ^{o}C (MOTA, 2005).

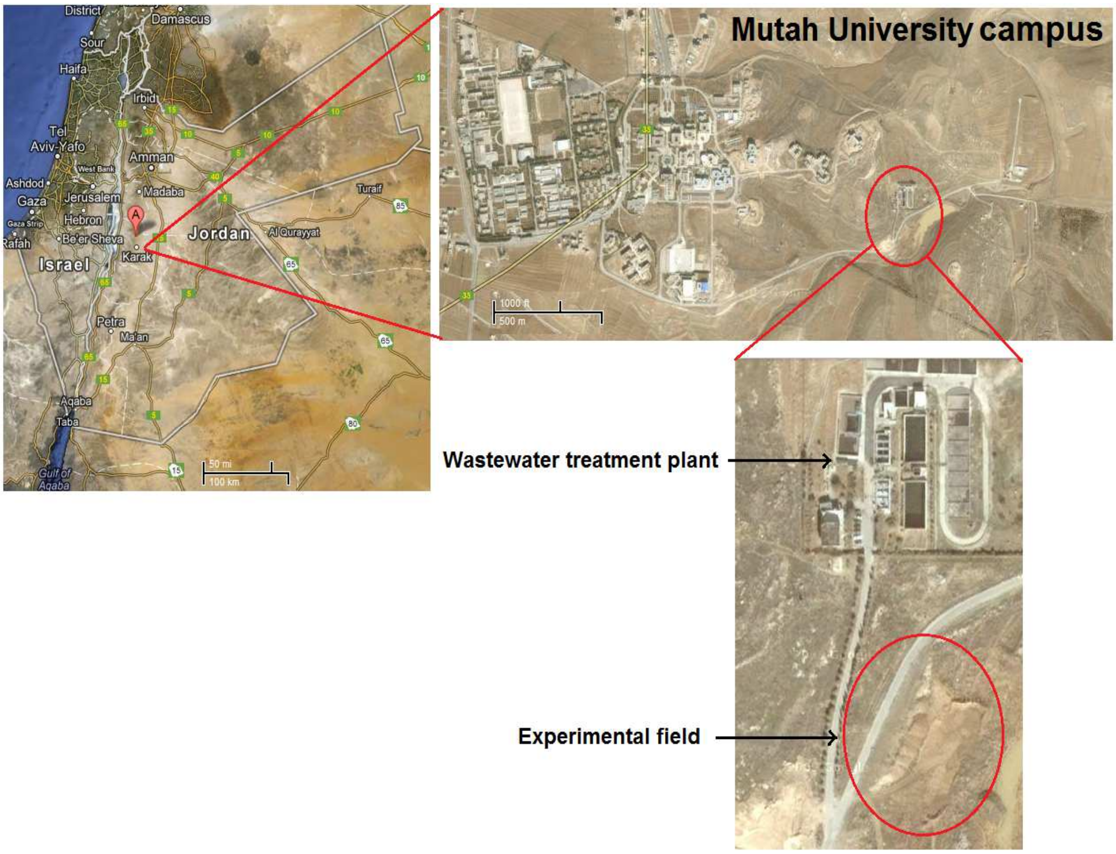


Figure 3.1: Experimental field location (Source: Google maps)

3.2 Field preparation

A test field for the application of SAP was prepared by excavating the upper 50 cm of the loamy soil layer in an area of 160 m^2 (20 m length x 8 m width). Then, sandy soil was applied at the same depth of 50 cm of the excavated area (**Figure 3.2 A**). The sandy soil was brought from a cultivation field found in between Gore Al-Safi and Wadi Araba, 150 km southern west of Mutah University campus. 260 plant holes with size of 25 cm × 25 cm × 25 cm were made in accordance with the eggplant agricultural practice (Lyimo, 2010); 75 cm were left between plants and rows (**Figure 3.2 B**). 96 from the 260 plant holes were used to cultivate eggplants under study. The latter, were subdivided into 24 test plots, each test plot with 4 plant holes. All test plots were distributed over the field completely randomized to compensate the impacts of soil variabilities. The plant holes of the test plots were filled with different ratios of the sandy soil-SAP mixture (w/w). In the same test plot, the 4 plant holes were filled with the same ratio of sandy soil-SAP mixture. The rest of plant holes, which were 164 plant holes, were used also for eggplant cultivation. They were situated in between and around the experimental test plots for natural field simulation. These eggplants were not considered within the study.

3.2.1 SAP application

The sandy soil-SAP mixtures were prepared with the following SAP concentrations (w/w): 0.2 and 0.4% SAP as well as no SAP (control). SAP concentrations were made by mixing 25 g and 50 g of SAP with 12.5 kg of sandy soil in a closed plastic container and then mixed well for 2 min by manual shaking. The soil-SAP mixture was then applied in each plant hole and pot with weight of 12.5 and 9 kg, respectively, as distributed randomly in the field (**Figure 3.2 C**).

3.2.2 Eggplant cultivation

Eggplant (*Solanum melongena*) saplings were planted in the plant holes and pots filled with sandy soil-SAP mixture without any pesticide or fertilizer applications (**Figure 3.3 A**).

3.2.3 Irrigation system

Irrigation intensity

The tests were run with two irrigation intensities. In 2010, the irrigation intensity was adjusted to 70% of the field water holding capacity twice a week within the test plot experiments. A drip irrigation system was applied and at every irrigation the soil water content was controlled with time domain reflectometer (TDR) equipped with EC20 probe (UMC, Germany) (**Figure 3.3 B**). Within the test plot experiments of 2011, the irrigation intensity was adjusted at the lowest possible intensity that allowed eggplants to survive at 0.0% SAP. All plants under study were irrigated manually with 45% of the field capacity once a week (**Figure 3.3 C**). Under the aspect that every luxurious water supply would interfere the approach of the field experiment, the habitus of eggplants in between and around the experimental plants was observed (0.0% SAP) and by this the irrigation intensity was adapted by decreasing or increasing the irrigation amount. By this, 45% of the field capacity was found to be the lowest possible irrigation intensity.

Irrigation water quality

The plants were irrigated with different types of irrigation water qualities (**Table 3.1)**. All of the artificial wastewaters with metal were immediately prepared in the field at the irrigation time using dilution from concentrated stock solution with metals which were freshly prepared in the laboratory. For adjusting the salt levels, exact weights of NaCl were dissolved in treated wastewater to achieve the needed EC values. The electrical conductivity (EC) threshold value for eggplant irrigation water was 4300 µS/cm (Guidelines for brackish water irrigation in the Jordan Valley, 2003), and the Cu and Zn threshold values were 0.2 mg/L and 2 mg/L, respectively (Ayers and Westcot, 1976, Helmer and Hespanhol, 1997). The composition of the artificial wastewater used for irrigation was checked by measuring the Cu and Zn concentrations every 4 weeks (in triplicate) following the standard method 3111 B (Greenberg, 2005). The water samples were collected in plastic vials, filtered using cellulose acetate syringe filter of 0.45 µm pore size, acidified and then analyzed using the flame atomic absorption (Atomic Ab, AA-6200, Shimadzu Scientific Instruments, Riverwood, Columbia, USA). The results were expressed by the means of the 3 measurements.

Table 3.1: Types of irrigation water quality used for irrigation purpose

Irrigation water quality	Description
Test plot experiment in 2010	
FW	Tap water from the public supply pipe was used for irrigation.
TW	Treated wastewater from the wastewater treatment plant at Mutah University used directly for irrigation purpose.
Test plot experiment in 2011	
FW	Tap water from the public supply pipe was used for irrigation.
TW	Treated wastewater from the wastewater treatment plant at Mutah University used directly for irrigation purpose.
AWS	Prepared by dissolving NaCl in treated wastewater; the EC was adjusted to be within the threshold value of 4000 µS/cm.
AWM	Prepared by dissolving Cu and Zn in treated wastewater. The Cu and Zn concentration were within the threshold values of 0.2 mg/L for Cu and 2 mg/L for Zn. A stock solution with 1000 mg/L was prepared and then a dilution was made at the time of irrigation to get the exact concentration needed.
AWSs	Prepared by adjusting the salt concentration at 2 times the threshold value (8000 µS/cm).
AWMs	Prepared by adjusting the Cu and Zn concentration at 3 times the threshold value (0.6 mg/L for Cu and 6 mg/L for Zn).

FW: Fresh water, TW: Treated wastewater, AWS: Artificial wastewater with intermediate salt addition, AWM: Artificial wastewater with intermediate heavy metal addition, AWSs: Artificial wastewater with high salt addition, AWMs: Artificial wastewater with high heavy metal addition.

A: Field preparation

B: Holes preparation for plants cultivation

C: SAP application

Figure 3.2: Field preparation for the test plot experiment and SAP application

A: Eggplant cultivation

B: Drip system irrigation in 2010

C: Manual irrigation in 2011

Figure 3.3: Eggplant cultivation and irrigation systems, **a:** Time domain reflectometer (TDR), **b:** Drip irrigation system, **c:** Plastic tanks for artificial wastewater preparation, **d:** Micropipette, **e:** Stock copper solution, **f:** Stock zinc solution, **g:** Graduated bottle for manual irrigation.

3.3 Physical and chemical characteristics of irrigation water and soil

3.3.1 Irrigation water

3.3.1.1 Total dissolved salts, electrical conductivity, pH and dissolved oxygen

The value of total dissolved salts (TDS) was measured according to the standard method 2540 C (Greenberg, 2005). 100 mL of a well-mixed sample were filtered through a 0.45 µm cellulose acetate membrane filters. The filtrates were then transferred into pre-weighed 200-mL beakers and evaporated to dryness in an oven at 105 ^{o}C for 24 h. The residues were immediately weighed after drying at 180 ^{o}C for 2 h and cooling to room temperature in a desiccator. The TDS for each sample was determined as the mass of solid normalized to the volume of water filtered (Atekwana et al., 2004). The pH, dissolved oxygen and electrical conductivity were measured in situ using the portable electrode meters (pH meter 31.5i, EC meter Cond 31.5i and O2 meter OXi 197, WTW GmbH, Weilheim, Germany).

3.3.1.2 Major anions and cations

The water samples were collected in plastic vials, filtered using cellulose acetate syringe filter of 0.45 µm pore size, acidified and stored in a refrigerator until analysis. The water samples were analyzed for Cl^-, F^-, NO_3^-, Br^- and SO_4^{2-} following the standard method 4110 C (Greenberg, 2005) using an Ion Chromatography Analyzer (IC) (761 compact IC, Metrohm AG, Ionenstrasse, Herisau, Switzerland), and for Na^+ and K^+ following the standard methods 3500-K B and 3500-Na B (Greenberg, 2005) using the flame photometry method (Flame photometry ATS 200MKI, Advanced Technical Service - ATS, USA) at Prince Faisal Center for Dead Sea, Environmental and Energy Research (PFC-DSEER), Mutah University, Jordan.

3.3.1.3 Biological and chemical oxygen demand

These parameters were provided by the controller of the wastewater treatment plant at Mutah University. The wastewater effluents are checked regularly for these parameters under the supervision of the Royal Scientific Society. The parameters are measured according to the standard methods 5210 D and 5220 D for the BOD_5 and COD, respectively (Greenberg, 2005).

3.3.2 Soil

3.3.2.1 Soil texture

The soil texture was determined using the hydrometer method (Gee and Bauder, 1986). 50 g of oven-dry soil samples were taken and then treated with 60 mL of 6% H_2O_2 (Riedel-de Haën, Germany) and heated in water bath at 80-90 ^{o}C in order to remove the organic matter. The process was continued until frothing disappeared. The residual contents were transferred to an 800-mL beaker and diluted with 400 mL distilled water, and then 100 mL of Calgon reagent (5% of sodium hexametaphosphate) (Fluka, Bochs, Switzerland) was added. The suspensions were stirred with magnetic stirrer for 20 min and then they were transferred into settling cylinder (1 L) which was sealed with Parafilm and shaken vertically for 1 min. The hydrometer was inserted immediately into the settling cylinder and after 40 s hydrometer reading (a) and suspensions temperature were recorded. Finally, after 2 h reading of hydrometer (b) and the suspension temperature was recorded again. The hydrometer readings were corrected according to its calibration temperature. The particles size distributions were determined as follows:

Silt % = (a-b)/c×100 (1)

Clay % = (b/c) ×100 (2)

Sand % = 100-(Silt % + Clay %) (3)

where, c is the weight of the oven-dry soil sample in gram after subtraction of the weight of the oxidized organic matter. Finally, the soil texture was determined using the textural triangle.

3.3.2.2 Water holding capacity

The water content at field capacity (Θ_{FC}) and water content at wilting point (Θ_{PWP}) were measured for the soil samples with pressure chambers (Soil Moisture Equipment, Santa Barbara, California, USA) at 33 and 1500 kPa, respectively. Finally, the samples were oven dried for 24 h at 105 ^{o}C and the bulk density (ρ_b) was determined. The available water was calculated as WHC= Θ_{FC} - Θ_{PWP} (4)

3.3.2.3 Bulk density

The bulk density was measured using the core method at the soil surface (Blake and Hartge, 1986). A core sampler of known volume was pressed in field, which was saturated with water up to the field capacity. The core samplers and its contents were removed carefully to preserve the natural structure, and the soil extending beyond the end of the sample holder was removed with a straight-edged knife. The soil volume was thus equal to the volume of the sample holder. Four samples were randomly taken from the sandy soil field. The core samplers were weighed to get the wet weight of the soil sample and then placed in an oven at 105 ^{o}C (Oven A:4.3, JP SELECTA S.A. - Laboratory equipment manufacturer Autovía A-2, Abrera, Barcelona, Spain) until constant mass was reached (the weight of the empty core sampler is well known). The soil samples were removed from the oven and allowed to cool down in the desiccator. The soil samples were then weighed on the balance immediately after removal from the desiccator. The bulk density was calculated according to the following equation:

Bulk density (BD) = Oven dry mass of soil / volume of soil (5)

3.3.2.4 Alkalinity

The pH value was measured according to the standard method SM 4500 H+B (Greenberg, 2005) by preparing 1:5 (soil:water) suspensions. The suspensions were prepared by shaking 10 g air-dry soil < 2 mm in 50 mL deionized water in a rotating shaker for 1 h at 15 rpm. The obtained pH values (pH meter 31.5i, WTW GmbH, Weilheim, Germany) was recorded when the equilibrium (stability in the reading) was reached while stirring with a mechanical stirrer (Rayment and Higginson, 1992). The soil pH was also measured by using 0.01 M $CaCl_2$ solution instead of deionized water in soil suspension preparation.

3.3.2.5 Electrical conductivity

The EC values were measured according to the standard method SM 2510 (Greenberg, 2005). The soil EC was determined by shaking a 1:2.5 (w/w) ratio of soil and deionized water. The mixture was homogenized for 30 min using a horizontal shaker and then left at room temperature until the soil settled down before EC measurement. The conductivity of the supernatant liquid was determined using the conductivity meter without disturbing the settled soil (EC meter Cond 31.5i, WTW, Germany) (Chapman and Pratt, 1961).

3.4 Field experiments

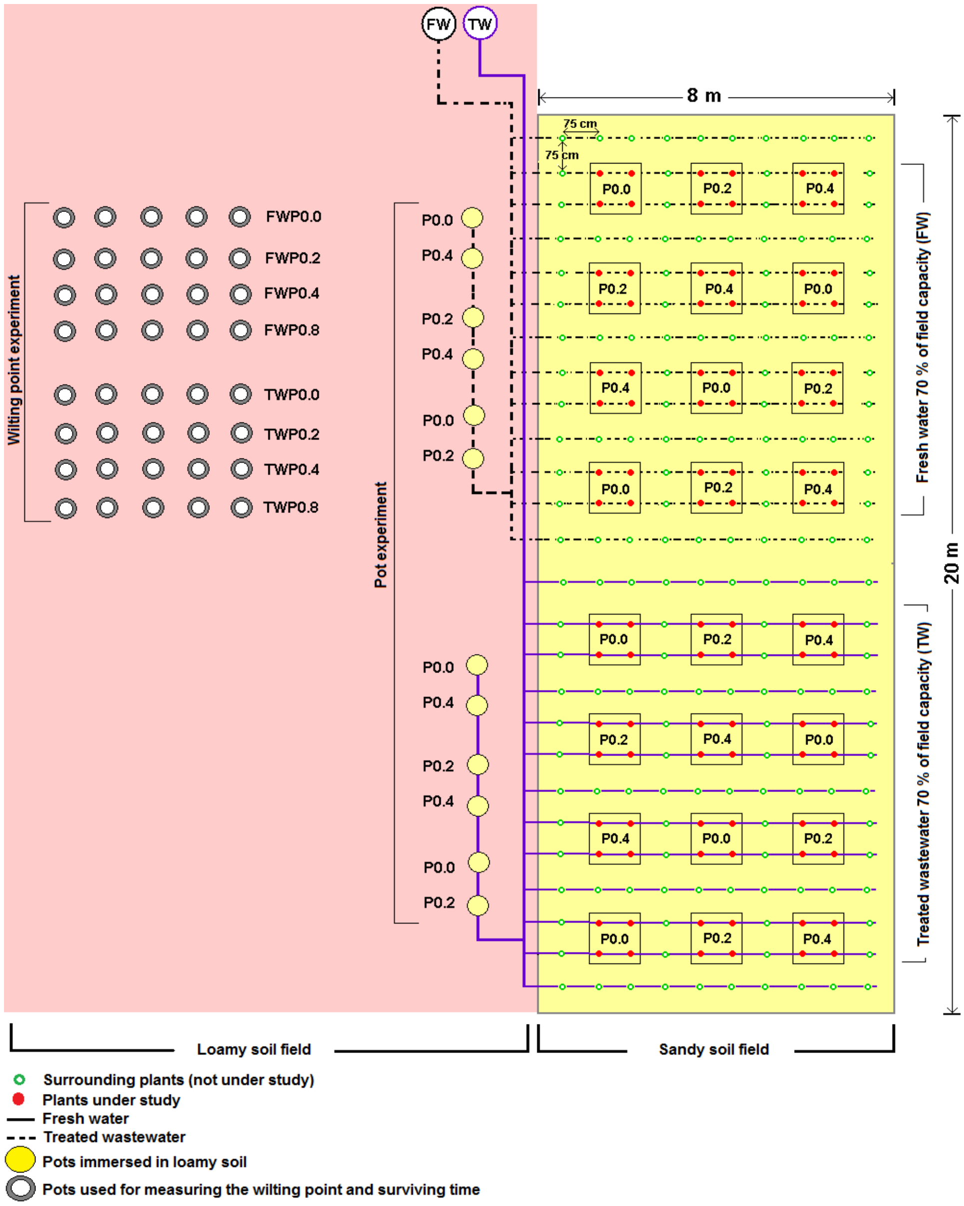
Two series of field experiments were carried out at PFC-DSEER, Mutah University. The first was within the vegetation period of 2010. In this period, the following three test series were carried out between June 1 and September 1: i) test plot, ii) pot and iii) wilting point experiments. The second field experiments were within the vegetation period of 2011. Two test series were carried out during the period from June 9 and September 9: i) test plot and ii) pot experiments.

3.4.1 Test plot experiments

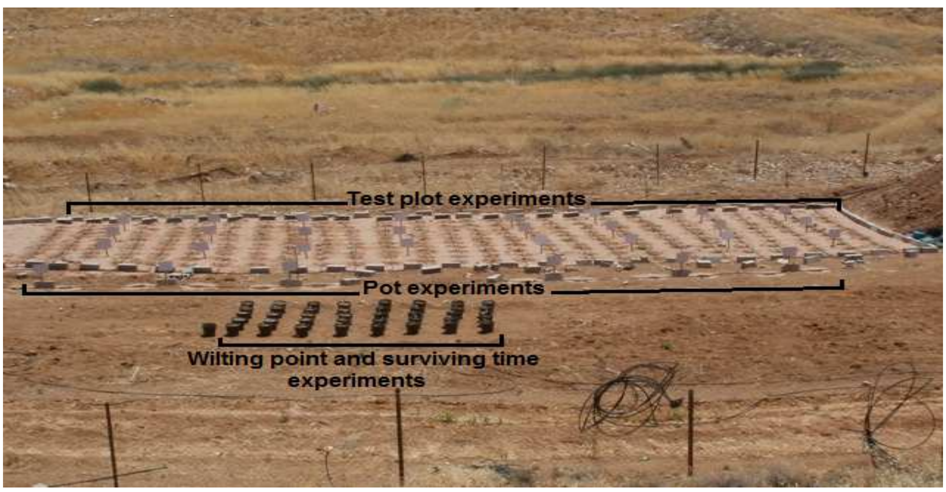
3.4.1.1 Test plot series in 2010

24 test plots were filled with different concentrations of sandy soil-SAP mixture (section 3.2 and 3.2.1). They were divided into two groups based on the irrigation water quality. The first group of 12 randomized test plots was irrigated with fresh water, and the second group of 12 randomized test plots was irrigated with treated wastewater. Within each group, 3 SAP concentrations 0, 0.2 and 0.4% were applied. By this, 4 test plot replicates resulted. Each test plot contained 4 eggplants cultivated in sandy soil amended with the same polymer concentration. In total, 96 eggplants (samples under study) were cultivated in the 24 test plots. The eggplants were irrigated with fresh water and treated wastewater with 70% of the field capacity twice a week using a drip irrigation system. The soil moisture was checked by a time domain reflectometer (TDR).

The growth rate parameters included plant height (cm), number of leaves, and stem diameter (mm). They were measured with intervals of two weeks during the 12 weeks vegetation period. After the 12-week vegetation period, samples of soil, eggplants, and irrigation water were collected (section 3.6) and analyzed at the Institute of Environmental and Sustainable Chemistry, TU Braunschweig. Additional chemical analysis and evaluation as well as bacterial study were carried out in the PFC-DSEER, Mutah University. **Figure 3.5** shows the field experiment design of 2010.



A



B

Figure 3.5: A: Field experiment design in 2010, **B:** Overall view of the test field

3.4.1.2 Test plot series in 2011

According to the irrigation water quality, the 24 test plots were divided into four groups: fresh water (FW), treated wastewater (TW), artificial wastewater with intermediate salt addition (AWS) and artificial wastewater with intermediate heavy metals addition (AWM). Each group contained two test plot replicates of each SAP concentration (w/w); 0, 0.2 and 0.4% SAP. In total six randomized test plots were generated in each group, with four eggplants cultivated in each test plot (**Figure 3.6**). A total of 96 eggplants were cultivated in the 24 test plots. The eggplants were irrigated manually to reach 45% of the field capacity with FW, TW, AWS and AWM once a week.

The growth rate parameters including plant height (cm) and stem diameter (mm) were measured with intervals of two weeks during the 12-week vegetation period. Thereafter, soil, eggplants, and irrigation water samples were collected (section 3.6) and analyzed in the Institute of Environmental and Sustainable Chemistry, TU Braunschweig. In addition, further chemical analysis and evaluation as well as bacterial study was carried out in the PFC-DSEER, Mutah University.

3.4.2 Pot experiments

3.4.2.1 Pot experiments in 2010

12 pots of 10-L volume and perforated bottoms were introduced randomly in the loamy field in order to have the same field conditions and then filled with two replicates of each SAP concentration (w/w): 0, 0.2 and 0.4% SAP. The pots were cultivated with one eggplant sapling for each pot. Based on the irrigation water quality, the 12 pots were divided into two groups: 6 pots were irrigated with fresh water and treated wastewater 6 with at 70% of the field capacity **(Figure 3.5 and 3.7 A)**.

3.4.2.2 Pot experiments in 2011

As in 2010, 12 pots of 10-L volume and perforated bottoms were installed in the sandy field and then filled with two replicates of each SAP concentration (w/w): 0, 0.2 and 0.4% SAP. The pots were cultivated with one eggplant sapling for each pot. Based on the irrigation water quality, the 12 pots were divided into two groups: 6 pots were irrigated manually with artificial wastewater with of salt concentrations and 6 with artificial wastewater of high heavy metal concentrations, both were irrigated manually to reach 45% of the field capacity (**Figure 3.7 B**).

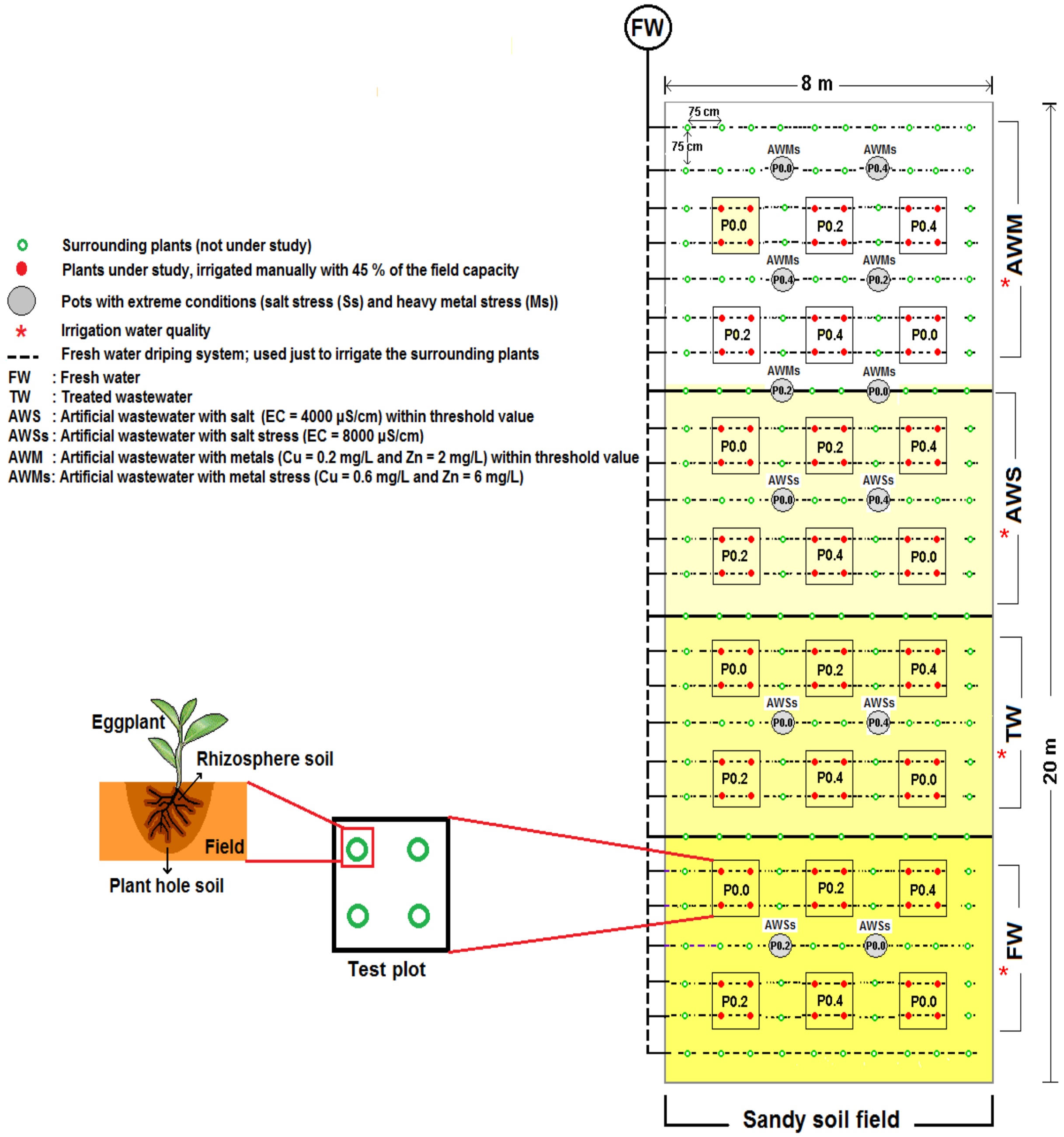
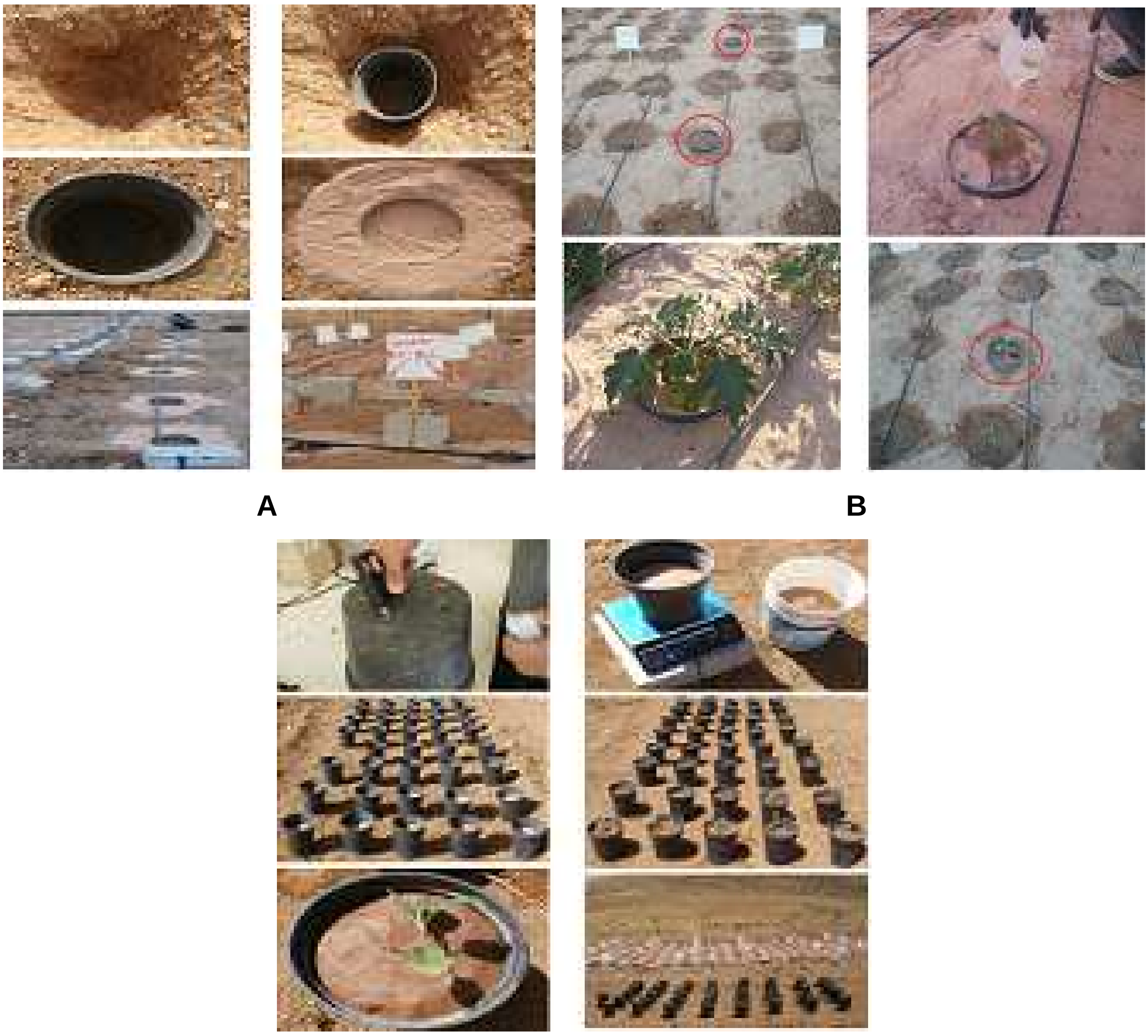


Figure 3.6: Field experiment design in 2011

3.4.3 Wilting point experiments

These experiments were carried out under field conditions in a special area section nearby the test field. 40 pots of 10-L volume were filled with 9 kg of sandy soil-SAP mixture (w/w) (0, 0.2, 0.4 and 0.8% SAP). The pots were bedded into the loamy soil. The 40 pots were divided into two groups according to the water irrigation quality of fresh and treated wastewater. Pots were maintained at field capacity until 3 weeks after plantation. Thereafter, water losses were monitored by weighing the pots until the plants reached the permanent wilting point. This was determined by early morning observations to ascertain whether the plants had recovered after irrigation overnight. The pot drainage bottom holes were closed with silicon to avoid water losses and the soil surface was covered with polystyrene beads to minimize evaporation (Anna et al., 2004) (**Figure 3.7 C**).



A **B** **C**

Figure 3.7: A: Pot experiment preparation in 2010, **B:** Pot experiment in 2011, **C:** Wilting point experiment preparation.

3.5 Growth parameters

Plant height (cm), number of leaves, and stem diameter (mm) were measured every two weeks in test plot and pot experiments during the experimental period of 12 weeks **(Figure 3.8 A)**.

3.6 Harvesting and sampling

3.6.1 Eggplant harvesting and sampling

At the end of the experimental period of 12 weeks, all of the 96 eggplants under study were harvested. The 4 eggplants from each test plot were collected together and then divided into stems, leaves, roots, and fruits. Thereafter, one representative sample was collected from each plant parts. One plant sample was also collected from each pot of the pot experiment. Each of the plant samples were divided into stems, leaves, roots, and fruits (**Figure 3.8 B**). Regarding the number of test plots and pots, the total number of plant samples was 96 and 48, respectively. The same number of plant samples was collected from both of the field experiments in 2010 and 2011.

At three random test plots, one sample of stems, leaves, roots, and fruits was also collected individually from each of the 4 plants (TWP0.2, FWP0.2 and AWMP0.2). These samples were collected for screening and verifying the homogeneity of the results for the samples that had the same treatment within the same test plot. 48 plant samples were collected for this purpose.

All of the fresh plant samples were gently washed with distilled water, oven dried at 60 ^{o}C until constant weight was reached, and kept in plastic bags in desiccators until transferred to Germany for element analysis.

3.6.2 Soil sampling

From the field experiment in 2010 the soil samples were representatively collected by homogenizing soils from the 4 plant holes at each test plot. The rhizosphere soils were collected in the same way. From the pot experiments, the plant hole soil and rhizosphere soils were collected individually from each pot.

Two additional samples of each plant hole soil and rhizosphere soil were collected from the test plot as well as from the pot experiments. One sample of the above mentioned two samples was collected in a sterile plastic bottle, which was kept in a refrigerator for not more than 24 h. The sample was used for the bacterial study. The other samples were used to carry out the chemical analyses (**Figure 3.8 C**). According to the number of test plots and pots, the total number of soil samples was 144 (**Table 3.2)**.

From the field experiment in 2011, two representative soil samples were collected from each test plot by homogenizing the plant hole soil and the rhizosphere soil from the 4 plant holes. Two soil samples from the pot experiment were also collected by homogenizing the pot soils and the rhizosphere soil samples. In addition, as in the field experiment of 2010, one sample of the above mentioned two samples has been collected in order to be used for the bacterial study. Regarding the number of test plots and pots, the total numbers of soil samples were 72 (**Table 3.2)**.

One soil sample was collected individually from each of the 4 plant holes of the following three random test plots: TWP0.2, FWP0.2 and AWMP0.2. These samples were collected for screening and to verify the homogeneity of the results. 12 soil samples were collected for this purpose. All of the soil samples were sieved < 2 mm, and kept in plastic bags in freezer until transferred to Germany for analysis.

A

B

C

Figure 3.8: A: Growth parameters measurement, **B:** Plant sampling and **C:** Soil sampling

Table 3.2: Number of soil samples collected from the field experiments in 2010 and 2011

Source of the soil	Purpose	Number of soil samples
Field experiments in 2010		
Plant holes of test plots	Chemical analysis	24
Rhizosphere of test plots	Chemical analysis	24
Plant holes of pots	Chemical analysis	12
Rhizosphere of pots	Chemical analysis	12
Plant holes of test plots	Bacterial study	24
Rhizosphere of test plots	Bacterial study	24
Plant holes of pots	Bacterial study	12
Rhizosphere of pots	Bacterial study	12
Total		144
Field experiments in 2011		
Test plots	Chemical analysis	24
Pots	Chemical analysis	12
Test plots *	Homogeneity test	12
Test plots	Bacterial study	24
Pots	Bacterial study	12
Total		84

* The soil samples were collected from the following three scattered test plots:

TWP0.2: Sandy soil amended with 0.2% SAP and irrigated with treated wastewater

FWP0.2: Sandy soil amended with 0.2% SAP and irrigated with fresh water

AWMP0.2: Sandy soil amended with 0.2% SAP and irrigated with artificial wastewater with metals

3.6.3 Water sampling

For irrigation water quality tests, three water samples of 50 mL were taken during the vegetation period 2010 and 2011. The samples were taken at the beginning, middle, and the end of the vegetation periods. The water samples were filtered using cellulose acetate syringe filter of 0.45 µm pore size, acidified, and stored in a refrigerator for element analysis.

3.7 Biomass of eggplants

All eggplant plant parts (roots, stem, leaves, and fruits) were cleaned by gentle washing with distilled water. The biomasses were dried in an oven at 60 ℃ until reaching a constant weight (Flanagan and Johnson, 2005).

3.8 Profit calculations from using SAP

The expected financial profits from using SAP in the present study were calculated for 0.2% SAP that showed the highest growth rate and fruit yields, and then compared with the control, which was irrigated with same irrigation water quality.

The calculations were performed based on the data of the test plot experiments, field area (160 m^2), number of plants (260), SAP application amount (25 g/plant), and the fruit yield produced (g/plant), and then extrapolated per hectare. Based on the agricultural practices followed in this study, 75 cm between plants and rows, 260 eggplants cultivated within 160 m^2, and 6.5 kg SAP used (25 g/plant). This was extrapolated for 1 hectare (10,000 m^2), the number of eggplants will be 16,250 plant/ha. The amount of SAP will be 406 kg/ha which costs 1,016 €/ha (**Table 3.3**).

Table 3.3: Eggplant fruit yield profits from test plot experiment when eggplants grown in control and in soil amended with 0.2% SAP and irrigated with different irrigation water qualities

Irrigation water quality and SAP concentration		Eggplants yield [g/plant]	Eggplants yield [kg/ha] and price of fruit yield per hectare in Euro [1 kg = 1 €]	Total income per hectare after subtracting SAP price [1,016 €/ha]*
FW	0.0%	138	2,243	2,243
	0.2%	173	2,803	1,787
TW	0.0%	148	2,405	2,405
	0.2%	173	2,803	1,787
AWS	0.0%	63	1,024	1,024
	0.2%	260	4,225	3,209
AWMs	0.0%	35	569	569
	0.2%	78	1,260	244
AWM	0.0%	130	2,113	2,113
	0.2%	220	3,575	2,559
AWSs	0.0%	0	0	0
	0.2%	90	1463	447

* The 0.0% SAP profits were not considered within this subtraction due to SAP was not used.

3.9 Bacterial studies

3.9.1 Total count, isolation, purification, and identification of bacterial communities

Using the techniques of serial dilution and Standard Plate Count (SPC), 1 g of soil was placed into a tube containing 9 mL of sterile saline solution (0.9% w/v NaCl). This tube was named 10^{-1} according to the dilution factor. From this tube, 1 mL of sample was serially diluted to 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5}, 10^{-6}, 10^{-7}, and 10^{-8} and then 0.1 mL from each dilution was inoculated into nutrient agar plates and spread using a sterile L–glass rod. The plates were incubated at 30 ^{o}C for 24 h (Incubator, J.P. Selecta, Spain). The colony morphology was observed and the isolated colonies were inoculated in a nutrient broth and incubated at 30 ^{o}C for 24 h. By this, each colony developed from one viable cell. Finally, these samples were further used to identify the morphological and biochemical characteristics of the organisms (Jayalakshmi et al., 2011).

Bacterial isolation and purification were done according to their colonial and cellular morphology, Gram stain, and the catalase and oxidase tests. The colonial and cellular morphology studies were carried out according to the techniques of serial dilution, spread plating, and smear slide technique (Collins and Lyne's, 2004).

According to their colonial morphology, 15 bacterial isolates were recovered from the irrigation water and field soil, and any tiny difference in colonial morphology was considered as a different isolate. Bacterial total count, isolation, purification, and identification for soil samples and irrigated water were done according to their colonial and cellular morphology and biochemical tests.

3.9.2 Biochemical identification

Regarding the laboratory capacity and time limitation, the biochemical identification for the bacterial isolates were carried out in the Sultan Medica Central Labs, Amman, Jordan. The following biochemical tests were conducted:

3.9.2.1 Sulfide-indole-motility

The media was prepared by dissolving 36.23 g of sulfide-indole-motility (SIM) medium (HIMEDIA, Mumbai, India) in 1 L distilled water. The medium was autoclaved at 121 ^{o}C and 15 Pa for 15 min. Thereafter, the bacteria were inoculated to test for hydrogen sulfide production, indole formation, and motility of the organism. One colony was picked on a sterile needle and then the needle was stabbed approximately two-thirds of the medium depth. To avoid ripping the medium, the needle was removed following the same path as the entry. The bacterium was incubated for 24-48 h at 37 ^{o}C (MacFaddin, 1980).

Hydrogen sulfide

If hydrogen sulfide is present, it will react with the sodium thiosulfate in the medium and the indicator, ferric ammonium citrate, will produce ferrous sulfide which, precipitates from the solution as a blackish stain. The presence of hydrogen sulfide typically means that the bacteria produce the enzyme cysteine desulfanase, which breaks up the cysteine in the medium into hydrogen sulfide (among other components).

Indole

The indole test was performed by adding Kovac's reagent (Arab company for medical diagnostics, Amman, Jordan) to the inoculated medium (SIM medium). The Kovac's reagent reacts with the indole to produce a pinkish-red or redish-purple ring around the top of the test tube. If indole is not present, there will be no color change. The presence of indole means that the bacteria produce tryptophanase enzyme, which breaks down tryptophan into smaller components one of which being indole.

Motility

The motility aspect of the test was done by checking the medium (SIM medium) for turbidity, or "fuzziness". If the medium has become fairly turbid throughout the medium, then the bacteria are motile. If the medium is clear and the only turbid appearance is in the stab line, then the bacteria are non-motile.

3.9.2.2 Urease

The media was prepared by suspended 42 g of urea medium (Biolab, Budapest, Hungary) in 1 L distilled water. The pH was adjusted to 6.8 at room temperature. The media was sterilized by filtration using a 0.45-µm membrane, but not autoclaved to avoid urea denaturation. Thereafter, loopfull of bacteria was inoculated in the urea medium and incubated for 24-48 h. With urease broth the ability of an organism to produce the exoenzyme urease was tested. It is a medium that hydrolyzes urea to ammonia and carbon dioxide. The broth contains two pH buffers, urea, a very small amount of nutrients for the bacteria, and the pH indicator phenol red. Phenol red turns yellow in an acidic environment and fuchsia in an alkaline environment. If the urea in the broth is degraded and ammonia is produced, an alkaline environment is created, and the medium turns pink (MacFaddin, 1980).

3.9.2.3 Citrate

The media was prepared by dissolving 24 g Simmons citrate medium (Biolab, Budapest, Hungary) in 1 L distilled water. The pH was adjusted to 6.9 at room temperature, sterilized at 121 ^{o}C under 15 Pa pressure for 15 m using autoclave, and then cooled in slanted position. Single isolated colony was streaked at the surface of the slant agar medium using a needle. Thereafter, the slant inoculated medium was incubated at 37 ^{o}C for 24-48 h.
The citrate test detects the ability of an organism to use citrate as the sole source of carbon and energy. Bacteria are inoculated on Simmons citrate agar. The medium contains sodium citrate and a pH indicator such as bromothymol blue. The medium also contains inorganic ammonium salts, which are utilized as sole source of nitrogen. Use of citrate involves the enzyme citritase, which breaks down citrate to oxaloacetate and acetate. Oxaloacetate is further broken down to pyruvate and carbon dioxide. Production of sodium bicarbonate as well as ammonia from the use of sodium citrate and ammonium salts results in alkaline pH. This results in a change of the medium’s color from green to blue (MacFaddin, 1980).

3.9.2.4 Oxidase

The oxidase disc (Arab company for medical diagnostics, Amman, Jordan) was placed on a microscopic slide. Well-separated young fresh colony was picked by cotton swab and then gently massaged onto the oxidase disc. The oxidase test identifies organisms that produce the enzyme cytochrome oxidase. This enzyme participates in the electron transport chain by transferring electrons from a donor molecule to oxygen. The oxidase reagent contains a chromogenic reducing agent, which is a compound that changes color when it becomes oxidized. If the tested organism produces cytochrome oxidase, the oxidase reagent will turn blue or purple within 10-15 s (MacFaddin, 1980).

3.9.2.5 Catalase

Well-separated young fresh colony was transferred to a clean microscopic slide using sterile loop. Using a Pasteur pipette, 1 drop of 3% hydrogen peroxide (Arab company for medical diagnostics, Amman, Jordan) was placed onto the colony on the microscope slide without mixing. The enzyme catalase decomposes hydrogen peroxide into oxygen and water. Excluding the *Streptococci*, most aerobic and facultative anaerobic bacteria possess catalytic activity. The positive results were expressed as producing gas bubbles after adding hydrogen peroxide to fresh bacterial colonies (Murray et al., 1998).

3.9.3 Endophytic bacterial study

A fresh sample from each plant part (roots, stems, fruits, and leaves) was surface sterilized for 10 s with 2% sodium hypochlorite followed by rinsing 5 times with sterile distilled water. The plant parts were dried with sterile paper towels, sterilized by wiping with 70% ethanol and flamed using Bunsen burner and followed by mashing or grinding with sterile saline solution. The techniques of serial dilution and Standard Plate Count Technique was followed the method of Zinniel et al. (2002).

3.9.4 Polymer degradation tests

Using the local isolates from the soil samples amended with SAP as a microbial source, a polymer degradation test was carried out at 30 ^oC by using the polymer as carbon source. Therefore, the carbon source was disarmed from the minimal media and then replaced with the polymer. The composition of the minimal culture medium was as follows: 2.0 g polymer, 1 g $(NH_4)_2SO_4$ (Park Scientific, Northampton, UK), 0.5 g K_2HPO_4 (Laboratory Rasayan, Anand, Gujart, India), 0.5 g KH_2PO_4 (Riedel-de Haën, Buchs, Switzerland), 0.2 g $MgSO_4 \cdot 7H_2O$ (BDH Laboratory Supplies, UK), 0.1 g NaCl (POCH, Gdanska, Poland), 0.1 g yeast extract (Fluka, Bochs, Switzerland), 2 mg $CaCl_2 \cdot 2H_2O$ (Fluka, Bochs, Switzerland), 2 mg $FeSO_4 \cdot 7H_2O$ (C.B.H Lab chemicals, Nottingham, UK), 7 mg $ZnSO_4 \cdot 7H_2O$ (C.B.H Lab chemicals, Nottingham, UK) and 2 mg $MnSO_4 \cdot 4H_2O$ (BDH Chemicals Ltd, Poole, UK) in 1 L of distilled water (Hayashi et al., 1993). The pH of the medium was adjusted to 7.0 with 1 M NaOH solution.

The bacterial isolates were cultivated aerobically at 30 ^oC for 24, 48, 72 and 96 h and then for one week in broth minimal medium. The broth culture then streaked on an agar plate containing the same minimal medium and incubated at 30 ^oC to develop colonies.

3.9.5 Isolation of metal resistant bacterial isolates

The *in vitro* study of metal uptake was based on measuring the adsorption and the biosorption by the field bacterial isolates. In case of cadmium the uptake comprises the amount of cadmium which can enter inside the bacterial cell while adsorption involves the amount of cadmium adsorbed on the bacterial cell membrane. Biosorption includes the sum of uptake and adsorption (Khleifat et al., 2009).

Selection of metal resistant strains (example Cd)

All bacterial isolates were grown in Nutrient Broth (NB) (Sigma-Aldrich, Saint louis, Missouri, USA) media containing cadmium nitrate with final concentration of cadmium 300, 700 and 1000 mg/L. The isolates were chosen that have the ability to survive and grow at highest concentration.

Cadmium biosorption by bacteria

The cadmium uptake was investigated in two local bacterial isolates species, *B. subtilis* and *K. pneumoniae*. The amounts of cadmium entered the cells was measured using the procedures described previously (Kanazawa and Mori, 1995; Khleifat and Homady, 2000) and considered as the amount of cadmium uptaken by the bacterial cell. It is expressed as µg/g biomass of bacteria.

Stock solutions of cadmium nitrate with different concentrations were prepared in 500 mL of distilled water. The final cadmium concentrations were 20, 40, 60, 80, 100, 200, 300, 400, 500, 600, and 700 mg/L. These solutions were sterilized in the autoclave (J.P. Selecta, Spain) at 121 ^{o}C, and 1500 kPa for 15 min. 24 polyethylene centrifuge test tubes of 50 mL volume were divided into two groups. Group A is used to test for uptake and group B for biosorption.

50 mg biomass of the cadmium resistant bacterial isolate was placed in each test tube and washed twice with 5 mL Ringer solution (Sigma-Aldrich, Louisiana, USA) using a refrigerated centrifuge (Hettich ROTINA 35 Tabletop Centrifuge, GMI, Bunker Lake Blvd. Ramsey, Minnesota, USA). The harvested bacteria were incubated for 1 h with 12 mL of the particular cadmium concentration at 37 ^{o}C and 150 rpm in shaking incubator (MDS100B, Meditry, China). At the end of incubation the bacteria were harvested and washed as follows: Group A was washed with 0.1 M ammonium acetate solution while group B was washed with deionized distilled water. Then, the biomass was re-harvested and decomposed by 1% nitric acid for 24 h, and then filtered with 0.45 µm pore size cellulose acetate filters. The cadmium content in the filtrate was measured by the means of flame atomic absorption instrument (Atomic Ab, AA-6200, Shimadzu, California, USA). The washed group A was used for measuring the cadmium uptake and the washed group B for measuring the cadmium biosorption. The cadmium adsorption was calculated by subtracting the amount of cadmium uptake from the amount of cadmium biosorption (Khleifat et al., 2009; Muayad et al., 2009).

3.10 Sorption isotherm

The sorption isotherms for Cd in Jordanian sandy soil with and without SAP amendment was investigated at the Institute of Environmental and Sustainable Chemistry, TU Braunschweig, Germany, for the sorption capacity and equilibrium. Cd solutions were prepared in soil solution and deionized water.

3.10.1 Preparation of solutions

The soil solution was prepared by adding 50 mL deionized water to 5 g of air dried soil with particles (< 2 mm) into 50-mL centrifuge vessels. The final soil:water ratio was 1:10. The vessels were rotated vertically at 1 rpm for 24 h at room temperature, followed by centrifugation at 3000 rpm for 10 min. The supernatant were then filtered with 0.45 µm pore size cellulose acetate filters (Sartorius, Göttingen, Germany). Cadmium nitrate (Merck, Darmstadt, Germany) was added to the soil solution to give final concentrations of 0.01, 0.02, 0.05, 0.1 and 0.2 mmol Cd which served as an adsorption solution later (Fritz et al., 1994). Pure Cd solution was prepared using pure deionized water to get the same Cd concentrations.

3.10.2 Adsorption tests

3.10.2.1 Adsorption experiment using soil solution

12 centrifuge vessels were washed with 2% nitric acid (VWR Prolabo, Fontenay-Sous-Bois, France) and then rinsed with 10 mM $CaCl_2$ solution (Merck, Darmstadt, Germany). 0.5 g of the Jordanian sandy soil was mixed with 2 mg of SAP to get a 0.4% (w/w) SAP polymer concentration. 25 mL of the 6 different Cd concentrations were transferred to the vessels in duplicate. The vessels were vertically rotated at 1 rpm for 24 h at room temperature followed by centrifugation at 3000 rpm for 10 min. The supernatants (equilibrium solutions) were filtered with 0.45 µm pore size cellulose acetate filters (Palágyi et al., 2005). The equilibrium solutions were acidified by 2% (v/v) nitric acid and then kept in a refrigerator until Cd analysis using inductively coupled plasma optical emission spectrometry (ICP-OES; see section 3.10.4).

After removing the supernatant, the vessels were re-weighted with the soil and the remaining Cd solution. The amount of Cd solution remaining within the sample was calculated by subtracting the weight of (dry) soil and the empty vessel from the total weight. This was used later in desorption calculations.

The above experiment was repeated following the same procedure but with sandy soil without any SAP amendments.

3.10.2.2 Adsorption experiment using pure solution

This experiment was carried out by the same procedure as described in 3.10.2.1. Instead of soil solution, Cd in deionized water was applied to the sandy soil-SAP mixture and pure sandy soil.

3.10.3 Desorption tests

A desorption experiments were carried out for the same sandy soils and sandy soil-SAP mixtures that were used for the adsorption experiments. 5 mL of 1 M NH_4NO_3 (Merck, Darmstadt, Germany) were added to the vessels containing the solids from the adsorption experiment. The slurries were rotated vertically at 1 rpm for 24 h at room temperature followed by centrifugation at 3000 rpm for 10 min. The supernatant (equilibrium solution) was filtered with 0.45 µm pore size cellulose acetate filters (Rao et al., 2008; Palágyi et al., 2005). The equilibrium solution was diluted with deionized water (1 mL equilibrium solution : 4 mL deionized water) and acidified by 2% (v/v) nitric acid. The solutions were kept in the refrigerator until Cd analysis by ICP-OES.
The desorbed Cd amounts were calculated by subtracting the residual Cd concentration that was found in the Cd solution after the adsorption experiment from the Cd concentration, which was measured in the desorption solution.

3.11 Determination of elements in water, soil, and plant samples

3.11.1 Sample preparation

Water samples
The water samples were collected from the field site, filtered with cellulose acetate syringe filter of 0.45 µm pore size, acidified with nitric acid (2 mL concentrated nitric acid per 100 mL water), and then stored in plastic vials in a refrigerator until element analysis.

Soil samples

All soil samples were sieved < 2 mm, oven dried overnight at 105 ^{o}C, ground by mortar and pestle, and then kept in plastic vials in the desiccator until digestion (Prell-Swaid and Schwedt, 1994).

Plant samples

Fresh plant samples were gently washed with deionized water and then oven dried at 60 ^{o}C until constant weight was reached. The plant samples were transferred into alsint crucibles and placed in the muffle furnace for 2 h at 550 ^{o}C. The plant ash was collected in plastic vials and stored in the desiccators until digestion (Temminghoff and Houba, 2004).

3.11.2 Sample digestion

200 mg of each of the soil and plant ash samples were transferred into microwave vessels. 13.3 mL of aqua regia (3.3 mL HNO_3 and 10 mL HCl) (VWR Prolabo, Fontenay-Sous-Bois, France) were added to each vessel. After finish of the gas bubble discharge, the vessels were inserted into the microwave oven (Microwave CEM corporation model MARSXpress, Kamp-Lintfort, Germany). The digestion method program was 2.5 min to reach 75 ^{o}C, 10 min to reach to 100 ^{o}C, 10 min to reach to 120 ^{o}C, 10 min to reach to 150 ^{o}C, and 10 min to reach to 200 ^{o}C. At this temperature the digestion was carried on for 20 min. The samples were filtered with PTFE syringe filters of 0.45 µm pore size (Sartorius, Göttingen, Germany). The clear digestion solutions were diluted to a volume of 20 mL with 10 % nitric acid and kept in plastic vials in the refrigerator until element analysis.

3.11.3 ICP-OES analysis

The digested samples were analyzed for trace elements using inductively coupled plasma optical emission spectrometry, ICP-OES (Vista-MPX, Varian, Germany; with simultaneous CCD detection; radial torch emission). Each element was measured at 5 different wavelengths. Selected wavelengths of lowest interferences for the investigated elements are shown in **Table 3.4**. Operating conditions for the ICP-OES are given in **Table 3.5**. For each working day a calibration curve ranging from 0.02 to 100 mg/L including 0.1, 0.4, 2, 10 and 20 mg/L standards was recorded for the elements Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Pb and Zn. For the P and S measurements standards from 0.5 to 100 mg/L including 1 and 10 mg/L were prepared. A solution of 10% HNO_3 was used as zero standard. Standards with different concentrations (1 and 10 mg/L) were run every 20 samples to check the stability of the ICP-OES. 10% HNO_3 was used as the rinsing solution after each measured sample.

Table 3.4: Selected wavelengths and the instrumental detection limits for ICP-OES

Element	Wave length [nm]	Instrumental detection limits [mg/L]
Ca	393.366	1
Cd	226.502	0.05
Cu	324.754	0.05
Fe	238.204	0.1
K	766.491	0.5
Mg	279.800	0.1
Mn	293.931	0.2
Na	588.995	0.5
P	177.434	0.5
Pb	182.143	0.2
S	180.669	0.5
Zn	213.857	0.1

Table 3.5: Optimized working conditions for the ICP-OES.

Power (kw)	1.2
Argon flow (L/min)	15
Auxiliary argon flow (L/min)	1.5
Neublizer pressure (kPa)	200
Plasma view	Radial
Viewing height (mm)	10
Replicate readtime (s)	20
Instrument stabilization delay (s)	30
Sample uptake delay (s)	30
Pump rate (rpm)	20
Rinse time (s)	30
Replicates	3
Neublizer	Concentric glass type sea spray
Spray chamber	Glass cyclonic

3.11.4 Method optimization and quality assurance

3.11.4.1 Artificial wastewater

Electrical conductivity

EC was measured in situ for the artificial wastewater that was used for irrigation purpose within the field experiment of 2011 every 3 weeks using the portable electrode meter in order to check the prepared EC value in the artificial wastewater.

Copper and zinc

Cu and Zn were measured in the artificial wastewater that was used for irrigation purpose within the field experiment of 2011 every 4 weeks using the flame atomic absorption in order to check the prepared concentrations in the artificial wastewater.

3.11.4.2 Type of samples collected from the soil

2 replicates of the plant hole and rhizosphere soil were sieved into < 2 mm particle size, ground by mortar and pestle, digested by microwave, and then analyzed for elements using ICP-OES.

3.11.4.3 Effect of soil grain size on element concentration

2 replicates of 4 soil samples (TWP 0.0%, TWP 0.2%, TWP 0.4% and FWP 0.2%) were sieved < 2 mm and < 125 µm, ground by mortar and pestle, digested in microwave oven and then analyzed for element analysis using ICP-OES.

3.11.4.4 Preparation of plant samples for element analysis

Fresh plant samples of leaf, stem, and root were gently washed with distilled water and then oven dried at 60 ^{o}C until constant weight was reached. Each plant sample was divided into two aliquots. The first was transferred into alsint crucibles and placed in the muffle furnace for 2 h at 550 ^{o}C. The second aliquot was kept as dry matter. Later, all of the plant samples (ash and dry matter) were collected in plastic vials and stored in the desiccator, digested in microwave oven, and then analyzed for Ca, K and Mg using ICP-OES.

3.11.4.5 Freundlich and Langmuir isotherms for Cd adsorption

To find out the fitted appropriate isotherm model for the equilibrium adsorption data, the samples resulted from the adsorption experiments were analyzed using ICP-OES. Thereafter, Freundlich and Langmuir adsorption isotherms were used to model the equilibrium adsorption data obtained for adsorption of Cd on sandy soil and sandy soil amended with 0.4% SAP (w/w).

3.12 Total Kjeldahl nitrogen in soil samples test plot and pot experiment

3.12.1 Sample preparation

Soil samples were sieved < 2 mm, oven dried overnight at 105 ^{o}C, ground by mortar and pestle, and stored in plastic vials in desiccators until digestion.

3.12.2 Sample digestion

3 g of the homogenized soils were applied to the digestion vessel (3 replicates). 1 Kjeldahl-tablet (5 g) (MERCK, Darmstadt, Germany), 3 boiling aids, and 10 mL sulfuric acid (Sigma-Aldrich, 96-97%) were added to each vessel. One of these three vessels was fortified with 50 mg phenylalanine (Sigma-Aldrich, Steinheim, Germany) to determine the recovery for quality assurance. One extra vessel with Kjeldahl, boiling aids, and sulfuric acid without sample was used as a control. All the vessels were fixed to the digestion unit (Digester 430, Büchi, Switzerland) inside the fumehood. The digestion method program was level 3 for 30 min, level 6 for 30 min, and then level 10 for 30 min or until the solution became clear and the white cloud inside the vessels disappeared. At the end of the digestion, all vessels were removed from the digestion unit and left in the fumehood to cool down for 30 min, and then 30 mL of distilled water were added to each vessel.

3.12.3 Sample analysis

One flask of 250 mL was prepared for each digestion vessel, each flask filled with 50 mL of boric acid (20 g/L) (MERCK, Darmstadt, Germany) and 200 µL mixed indicator 5 (MERCK, Darmstadt, Germany).

The distillation unit (Distillation Unit K-355, Büchi, Switzerland) was warming up by fixing vessel with distilled water for 5 min and 100 steams power. For the automated distillation, each vessel was fixed to the distillation unit with its own flask. The following parameters were programmed: 110 mL of 3 M NaOH (Carl Roth, Karlsruhe, Germany), 10 min distillation time, and 40 steam power. At the end of distillation, the flasks were titrated with 0.1 M HCl to grey (weakly pink) endpoint. The used volume of HCl for each flask was notified and then applied in the following equation to calculate the total Kjeldahl nitrogen (TKN).

$TKN = ((V_1 – V_0) \times c \times M_N) / m$ (6)

V_0: Volume of HCl used in the blank test [mL]

V_1: Volume of HCl used in the titration of the blank sample [mL]

m: Mass of the blank sample [g]

c: Concentration of HCl [mol/L]

M_N: Molar mass of N [g/mol]

3.13 Total organic carbon in test plot and pot experiment soil samples

3.13.1 Sample preparation

Soil samples were treated with an excess of 4 M hydrochloric acid for removing carbonates. By heating on a hot plate at 100 ºC the excess HCl was removed. The samples were dried in an oven at 105 ºC overnight. After cooling, the samples were ground using mortar and pestle, and then kept in plastic vials in desiccators until TOC analysis.

3.13.2 Sample analysis

TOC was determined by means of the organic carbon analyzer (C-Analyzer Dohrmann DC-90, Dohrmann, Santa Clara, CA, USA). For this purpose, well defined weights of soil samples were combusted in an oxygen stream at 900 ºC. The released carbon dioxide was subsequently detected by a non-dispersive infrared detector. The TOC amount was calculated based on an external standardization. The calibration curves (4 to 190 µg carbon) were recorded using a mixture of oxalic acid dehydrate and aluminum oxide (Merck, Darmstadt, Germany) in a ratio (1:9), respectively. Finally, the results were expressed in % of dry substance according to the following formula.

$TOC (\%) = (W_b/W_a) \times 100$ (7)

where:

W_a: initial weight (µg)

W_b: amount of carbon (µg)

3.14 Microbial activity of the soil samples

All soil samples were wetted to 50% of the field capacity for 48 h and incubated in a beaker covered with aluminum foil at room temperature to remobilize the microbes. Using an OxiTop® OC 110 control system with OxiTop®-C measuring head (WTW, Weilheim, Germany), the microbial activity of the soil was determined as a function of oxygen pressure decrease, which is due to the microbial respiration process initiated by a certain substrate. This process is known as substrate induced respiration (SIR) (Stenström et al., 1998). For this purpose, 50 g dry substance (ds) of the prepared soil samples was applied into 1 L screw capped glass bottles. 0.5 g of substrate (84% glucose, 14% diammonium sulfate and 2% potassium dihydrogen phosphate) was added and mixed well for 1 min with the soil. Afterwards, 8 mL of a 45% KOH (Carl Roth, Karlsruhe, Germany) solution was placed into the OxiTop trap in order to absorb the released carbon dioxide, which evolves due to the respiration process. The OxiTop was tightly screwed to the bottle and the device incubated in the incubator at 20 ºC for 24 h. The pressure decrease developed due to the consumption of the oxygen was recorded and the microbial activity was expressed in mg O_2/(kg h) (DIN ISO 17155: 2003-06).

4. Results and discussion

The presented research activities focused on the amendment of superabsorbent polymers on soils under the main aspect of improving the irrigation efficiency for eggplant cultivation in Jordan due to the water scarcity in this arid area. Furthermore, the reuse of treated wastewater instead of fresh water for irrigation purpose was investigated to assess its environmental impacts on plants and soil. Besides plot and pot experiments under field conditions, laboratory tests were performed to advance the knowledge about the effects of superabsorbent polymers in soil.

4.1 Water analysis

Treated wastewater from Mutah University was used for irrigation. In a first step, the quality was analytically checked and compared with the Jordanian standards of irrigation water quality to determine its suitability for reuse.

4.1.1 Quality of treated wastewater

Three samples from treated wastewater were analyzed parallel to fresh water as control on total dissolved salts, electrical conductivity, biological and chemical oxygen demand, pH, and dissolved oxygen. The parameters were used as indicators for the suitability of wastewater reuse. The analyses showed that the total dissolved salt concentration of treated wastewater was higher than that of fresh water, i.e., 500 and 250 mg/l, respectively. This result was reflected by the higher electrical conductivity of 872 vs 511 µS/cm **(Table 4.1).** BOD_5 and COD of the treated wastewater were 7 and 32 mg/L, respectively. Differences of pH and O_2 values between the treated wastewater and fresh water were indiscernible, reflecting the low contamination of the wastewater at the campus of Mutah University and the high quality of reclaimed water after the treatment.

The Jordanian standard for the reuse of reclaimed water indicates a TDS threshold of < 2000 mg/L to be acceptable for the reuse in irrigation of vegetables (Al-Zboon and Al-Ananzeh, 2008). The treated wastewater from Mutah University was within the TDS specifications, and thus, could be used for irrigation of eggplants. The TDS value of treated wastewater met the average value of domestic drinking water in Jordan which is 580 mg/L. In general, the Jordanian wastewater is characterized by a high salinity and the TDS ranges from 700-1200 mg/L. This is caused by the high salinity of domestic drinking water. The situation is exacerbated by the use of wastewater stabilization ponds that have high evaporation rates, especially during the summer season (Ammary, 2007).

BOD_5 and COD were within the range as stipulated by the Jordanian standard for irrigating vegetables which are 150 mg/L and 500 mg/L, respectively (Al-Zboon and Al-Ananzeh, 2008). pH and O_2 values were within the accepted range for agricultural purpose according to the Guidelines for municipal wastewater irrigation (2000). By this, the pH should be 6.5-8.5 and O_2 > 2 mg/L. The EC value allows the use of the treated wastewater for the agricultural purpose according to the Guidelines for Municipal Wastewater Irrigation (2000) which mentioned EC < 1000 µS/cm.

Table 4.1: Total dissolved salts, electrical conductivity, biological and chemical oxygen demand, pH, and O_2 measurements in fresh water and treated wastewater (means ± SD, n = 3)

Water quality	TDS [mg/L]	BOD_5 [mg/L]	COD [mg/L]	pH	O_2 [mg/L]	EC [µS/cm]
FW	256 ± 15	-**	-**	7.6 ± 0.11	4.3 ± 0.25	510.6 ± 1.2
TW	500 ± 84	7 ± 0.1	32 ± 2.1	7.7 ± 0.05	4.4 ± 0.20	872.3 ± 2.5
Jordan standard*	< 2000	150	500	6.5-8.5	> 2	< 1000

*: (Guidelines for Municipal Wastewater Irrigation, 2000)

**: Not measured

4.1.2 Major anions and cations

The major anions and cations were determined for fresh water and treated wastewater from Mutah University (**Table 4.2**). Higher concentrations of all analyzed ions were found in treated wastewater compared with fresh water. Additionally, the treated wastewater quality was compared with the Jordanian standards for treated wastewater that can be used for irrigation of crops (JISM, 2008). It was found that except of nitrate the treated wastewater quality used for the irrigation of eggplants is within the Jordanian guideline values.

Table 4.2: Major anions and cations in treated wastewater and fresh water

Water quality	Cl^- [mg/L]	NO_3^- [mg/L]	PO_4^{3-} [mg/L]	SO_4^{2-} [mg/L]	Na^+ [mg/L]	K^+ [mg/L]
FW	48.4	17.9	B.D	26.4	22.8	2
TW	100.7	96	15.5	41.3	28.3	14
Jordan standard*	400	80	30	500	230	80

*: (JISM, 2008)

B.D: Below detection limit of 0.5 mg/L

4.1.3 Chemical element analysis

Three replicates of treated wastewater and fresh water used in the test plot and pot experiments in 2010 were analyzed for chemical elements. With the exception of Zn, higher element concentrations were found in treated wastewater. In spite of the differences, the treated wastewater values are within the Jordanian guidelines for irrigation purposes (**Table 4.3**).

Table 4.3: Chemical element concentrations in treated wastewater and fresh water used for irrigation in 2010

Water quality	Elements concentration [mg/L]							
	Ca	Fe	K	Mg	Na	P	S	Zn
FW	64	0.13	1.6	21	29	0.3	9	0.23
TW	72	0.14	17	23	85	5	22	0.06
Jordan standard*	230	5	80	100	85	-**	-**	5

*: (JISM, 2008)

**: Concentrations not reported in the Jordanian guidelines.

The rest of elements Mn, Cd, Cu and Pb were below detection limit (see section 3.10.3).

The irrigation water qualities used in the test plot and pot experiments in 2011 were analyzed with three replicates during the vegetation period, i.e., at the beginning, middle, and at the end of the vegetation period. The irrigated waters were within the Jordanian guidelines for reuse of treated wastewater for irrigation purposes except the concentrations of Cu and Zn in AWM and AWMs as well as the concentrations of Na in AWS and AWSs (**Table 4.4**). The comparison shows that treated wastewater from Mutah University is near the fresh water quality. Therefore, artificial wastewaters with high metal and salt concentrations were additionally prepared in order to cause metal and salt stress on the eggplants of test plot and pot experiments under field conditions.

Table 4.4: Element concentrations in fresh water, treated wastewater and artificial wastewaters used for irrigation in 2011

Element	Element concentrations [mg/L]					
	FW	TW	AWM	AWMs	AWS	AWSs
Ca	43.5	50.4	50.4	50.6	50.3	50.0
Cd	B.D	B.D	B.D	B.D	B.D	B.D
Cu	B.D	B.D	0.38	1.17	B.D	B.D
Fe	0.06	0.044	0.068	0.095	0.148	0.041
K	2.02	15.1	15.0	15.1	17.8	23.7
Mg	24.3	28.9	28.9	29.4	28.1	28.1
Mn	B.D	0.047	0.049	0.048	0.049	0.045
Na	18.4	55.3	55.6	55.8	1275	1995
P	0.152	4.22	4.27	4.2	4.17	4.21
Pb	0.046	0.036	0.024	B.D	0.03	B.D
S	11.6	26	25.8	25.9	25.9	26.0
Zn	0.54	0.826	6.13	14.6	0.839	0.907

B.D: Below detection limit (see section 3.10.3)

4.1.4 Quality of artificial wastewater

During the irrigation period of 2011 the quality of artificial wastewaters used for irrigation was checked permanently. In addition to screening the pH and electrical conductivity values the copper and zinc concentrations were analyzed.

pH and electrical conductivity

The pH and EC of the artificial wastewater were screened and measured within the field experiment every 3 weeks. The artificial wastewater with salt (AWS) and artificial wastewater with salt stress (AWSs) were adjusted to 4000 and 8000 µS/cm, respectively. The salt concentration in AWS and AWSs were proved to be within adjusted values **(Table 4.5)**. For the rest of irrigation water quality, the EC values as well as the pH values were within the accepted range according to the Guidelines for Municipal Wastewater Irrigation (2000).

Table 4.5: pH and electrical conductivity measurements in the fresh water, treated wastewater and artificial wastewaters (means ± SD, n = 4)

Irrigation water	EC [µS/cm]	pH
FW	0.5 ± 0.001	7.2 ± 0.13
TW	0.9 ± 0.003	7.0 ± 0.05
AWS	4.3 ± 0.248	7.0 ± 0.09
AWSs	8.1 ± 0.142	7.1 ± 0.57
AWM	0.9 ± 0.002	7.1 ± 0.14
AWMs	0.9 ± 0.004	7.1 ± 0.41

Copper and zinc

Cu and Zn concentrations were measured in the artificial wastewater used in the field experiments in 2011 every 4 weeks. The results showed that the Cu and Zn concentrations were within the expected values and confirmed the prepared concentrations in the artificial wastewater **(Table 4.6).**

Table 4.6: Cu and Zn concentrations in fresh water, treated wastewater and artificial wastewaters (means ± SD, n = 3)

Irrigation water	Cu [mg/L]	Zn [mg/L]
FW	0.06 ± 0.04	0.35 ± 0.18
TW	0.03 ± 0.01	0.24 ± 0.04
AWS	0.06 ± 0.02	0.21 ± 0.09
AWSs	0.04 ± 0.01	0.15 ± 0.12
AWM	0.24 ± 0.02	2.86 ± 0.07
AWMs	0.64 ± 0.01	6.16 ± 0.44

4.2 Soil analysis

4.2.1 Soil texture

The soil texture was determined using the hydrometer method (Gee and Bauder, 1986). Using the soil texture triangle the soil was identified as sandy soil with sand 90.7%, silt 9.1%, and clay 0.2%.

4.2.2 Water holding capacity, wilting point, and available water

The water holding capacity (WHC) was monitored in the field using the time domain reflectometer (TDR) and also with pressure chambers at 33 kPa under laboratory conditions. The WHC was 14% for the control (sandy soil without SAP amendment) and increased proportionally to the increase of SAP concentration (**Figure 4.1)**. The WHC of the sandy soil amended with 0.2, 0.4 and 0.8% SAP (w/w) increased by 21, 50 and 143%, respectively, compared with the control. The effect of the SAP amendment on WHC was in agreement with the observations of Hüttermann et al. (1999). They found that the increase of SAP amendment from 0.04, 0.08, 0.12, 0.2 to 0.4% triggered an exponential increase in the WHC of a sandy soil. This response of WHC on the concentration of hydrogel was also very pronounced when sandy loam soils were amended with 0.1, 0.2 and 0.3% hydrogel, the WHC increased by 17, 26 and 46%, respectively, compared with the control (Akhter et al., 2004). Same authors observed an increase of 23, 36 and 50% of WHC in loam soil with an addition of 0.1, 0.2 and 0.3% hydrogel, respectively. This affinity of SAP for water can reduce the amount of irrigation water otherwise lost by evapotranspiration or deep percolation (Dorraji et al., 2010).
The permanent wilting point was given as the lower limit of soil water availability related to suction at 1500 kPa. The results of wilting point experiments were 10, 10, 17 and 30% at 0, 0.2, 0.4 and 0.8% SAP (w/w), respectively. The wilting point of eggplants that grew in sandy soil amended with 0.2, 0.4 and 0.8% SAP (w/w) increased by 0, 70 and 200%, respectively, compared with the control (**Figure 4.1**). These results are in agreement with Abedi-Koupai and Asadkazemi (2006), who found the wilting point in sandy loam soil amended with 0.4 and 0.6% (w/w) of the hydrophilic polymers Superab A200 were 2.4 and 3 fold of the control, respectively. In contrast, the opposite was observed by Akhter et al. (2004). The wilting point decreased by almost 60% in sandy loam and loam soils when amended with 0.1, 0.2 and 0.3% polyacrylamide hydrogel concentrations.

The above-mentioned results of WHC and wilting point were used to calculate the available water for the eggplants. With the exception of adding 0.2% SAP, the available water is not affected by increasing the polymer concentration. This can be interpreted to result from the increase of the wilting point parallel to WHC by the increase of SAP concentration. The highest available water for the plant was found at 0.2% SAP. This is due to an identical wilting point of the control and 0.2% SAP and at the same time a marked increase in the WHC at 0.2% SAP (**Figure 4.1**). Identical results were found by Sivapalan (2001). According to these studies, the WHC of siliceous sand (86% sand and 6% clay) significantly increased by 23 and 95% after the addition of 0.03 and 0.07% of synthetic anionic acrylic copolymer

(ALCOSORB® 400), respectively. Sivapalan (2001) ascribes the effect to the increase in pressure from 0.01 to 1.5 MPa which enables the soil amended with polymer to retain more water. Otherwise, the amount of water released from this soil did not significantly increase indicating that there was only a small difference in the available water. In contrast to the report of Akhter et al. (2004), the amendment with hydrogel of 0.1, 0.2 and 0.3% increased the WHC of sandy loam and loam soils and thus the plants available water. The obvious discrepancies between different authors concerning the stored water releases under different conditions cannot be explained at present.

The results of the present study showed also that eggplants survived longer in sandy soil amended with SAP. The permanent wilting point (PWP) was delayed by 6, 6, and 9 days in sandy soil amended with 0.2, 0.4 and 0.8% SAP, respectively (**Figure 4.2**). These findings were in agreement with the observation of Akhter et al. (2004), which showed that the PWP was delayed by 1.5, 2 and 5 days in sandy loam soil amended with hydrogel of 0.1, 0.2 and 0.3%, respectively.

The 0.8% SAP application showed the longest survival time for eggplants of 9 days. However, this concentration was excluded from the test plot experiments, because the eggplant remained alive, but without growth (**Figure 4.3**).
Based on the results of WHC, PWP, and available water, the 0.2% SAP concentration proves to be best suited for Jordanian sandy soil amendments. It increases the WHC and the available water as well as delayed the PWP for 6 days, compared with the control.

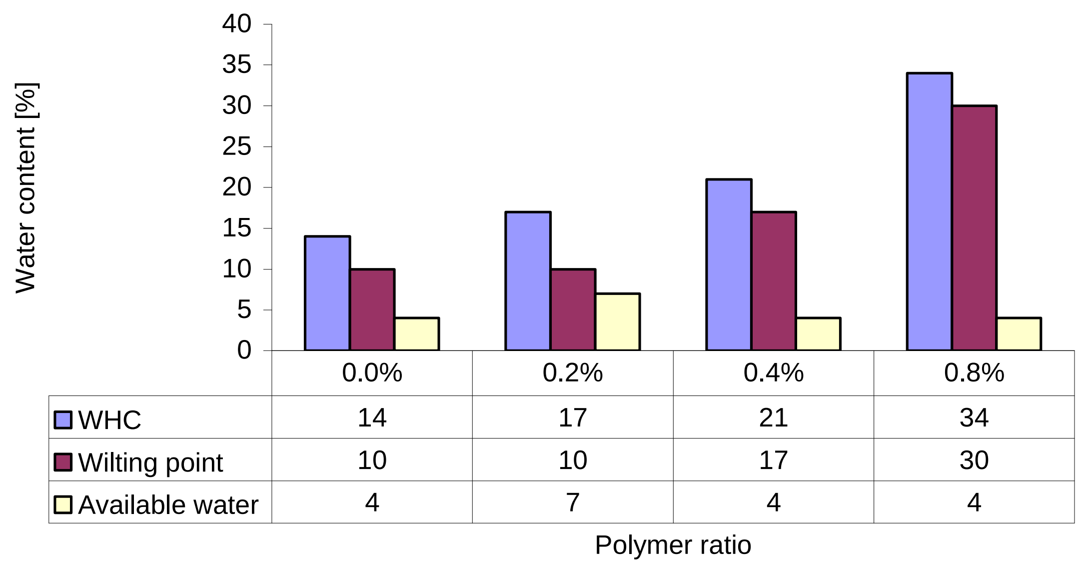


Figure 4.1: Effect of SAP concentrations on the water holding capacity, wilting point, and available water in Jordanian sandy soil.

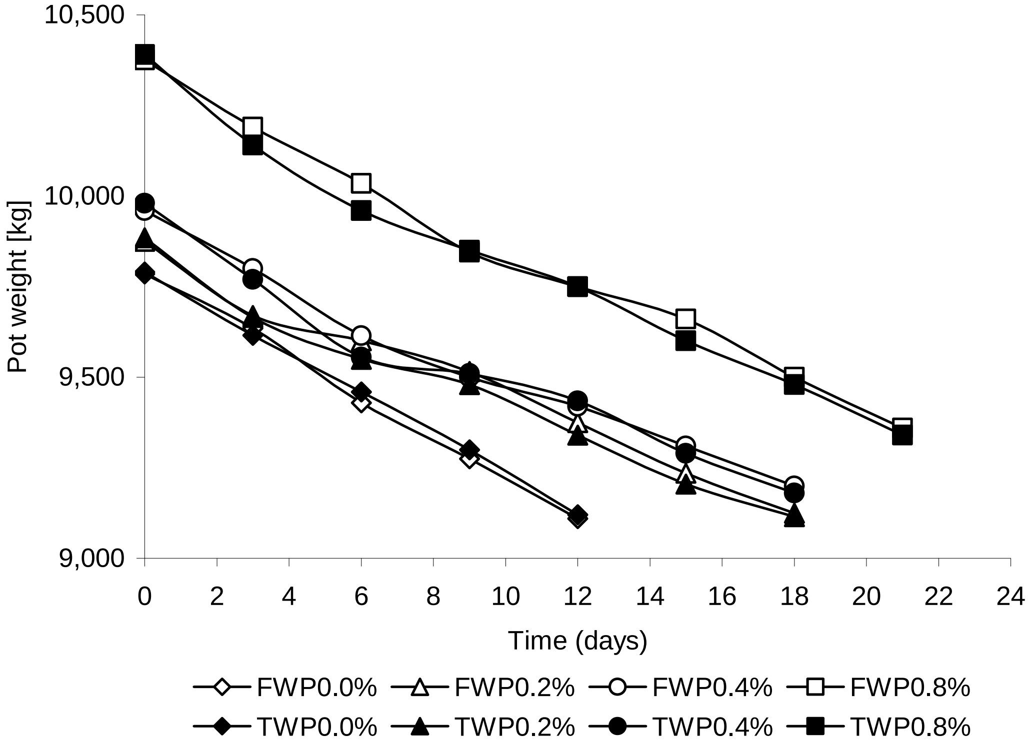


Figure 4.2: Surviving time of the eggplants grown in sandy soil amended with different concentrations of SAP, and irrigated with fresh water and treated wastewater.

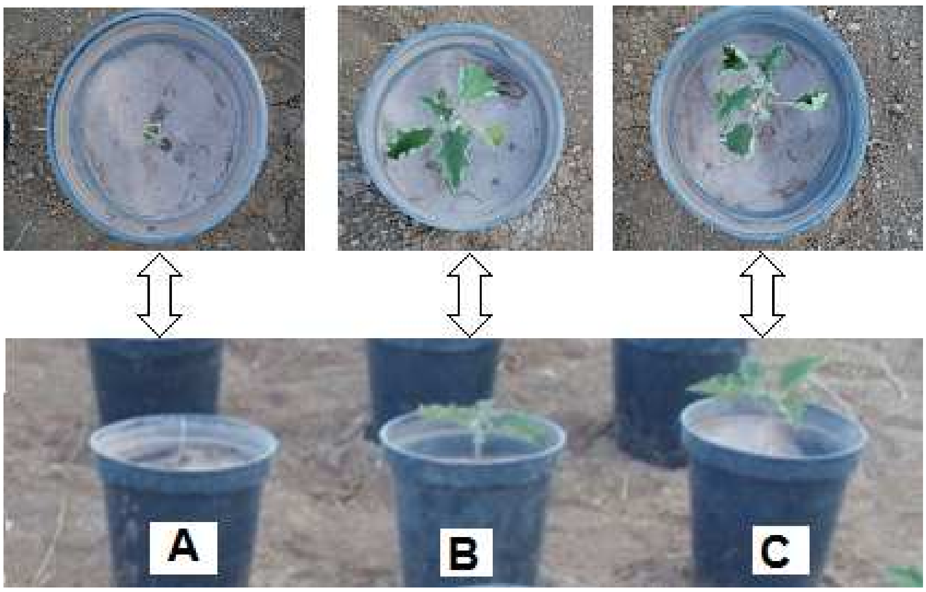


Figure 4.3: Growth behavior of eggplants planted in sandy soil-SAP mixture (w/w) during wilting point experiment; **A:** 0.8% SAP, **B:** 0.4% SAP, **C:** 0.2% SAP

4.2.3 Bulk density

The bulk density tests were performed with 4 replicates. According to the USDA (2008), the range of ideal bulk densities for plant growth is < 1.6 g/cm^3. Jordanian sandy soil showed an average bulk density of 1.58 g/ cm^3 and, therefore, is suitable to carry out the experiments.

4.2.4 pH and electrical conductivity

The pH of plant hole and rhizosphere soils from the test plot experiment in 2010 raised to about 9 regardless of the irrigation water quality and SAP concentration, compared with the original soil, which showed a value of 8.3 (**Table 4.7**). No correlation was observed between the pH and SAP concentrations regardless of the irrigation water quality. These findings were in agreement with the observation of Bai et al. (2010), who found the pH of sandy clay loam soil amended with different concentrations of potassium polyacrylate polymer (0.05, 0.1, 0.2 and 0.3% w/w) was increased by 0.9-7.6%. A positive correlation with polymer concentrations was indiscernible. Variations in soil pH were observed by the same author when the soil was amended with different polymers, which was interpreted to be due to the contrasting chemical structures of the hydrogels.

A decrease of the electrical conductivity (EC) was observed in the plant hole and rhizosphere soils by 70-80% regardless of the irrigation water quality and polymer concentration. As an exception, the concentration 0.4% SAP showed the lowest percentage of decrease (48-53%) at both irrigation water qualities (**Table 4.7**). This effect can be explained due to irrigation practices effective for a period of 12 weeks and led to wash soluble salts from the soil and then can decrease EC (USDA, 2011).

The most interesting result within the sandy soil amended with SAP was the increase of EC with increasing polymer concentration regardless of the irrigation water quality and the type of soil samples. The results showed an increase in EC by 16 and 37% in the plant hole soil irrigated with treated wastewater and amended with 0.2 and 0.4% SAP, respectively. Using fresh water irrigation the increase was 14 and 164%, respectively. The same trend was observed also within the rhizosphere soil samples (**Table 4.7**). These results are consistent with the findings of Shahid et al. (2012), who found the EC of sandy loam soil amended with 0.1, 0.2, 0.3 and 0.4% (w/w) poly(acrylamide-co-acrylic acid)/$AlZnFe_2O_4$ was increased by 6, 11, 45 and 56%, respectively. Opposite results were reported by Dorraji et al (2010). They noticed that increasing the polymer concentrations resulted in the reduction of soil electrical conductivity. The EC decreased by 15.3, 20.0 and 16.9% after 0.6% polymer application in sandy soil, loam, and clay soil, respectively. Bai et al. (2010), while studying the characteristics of superabsorbent polymers, i.e., potassium polyacrylate, sodium polyacrylate, sodium polyacrylate/clay mineral, and polyacrylamide/attapulgite clay, observed no significant differences for EC with the different concentrations of polymer. They linked this behavior to the chemical structures of the superabsorbent polymers and characteristics of the soils.

In this study, the highest EC value was found within sandy soil amended with 0.4% SAP concentration and irrigated with fresh water. This unexpected result has no explanation at present. Bai et al. (2010) reported, SAPs have different effects on the pH and EC of soils depending on the synthetic materials and chemical structure of the SAP and the physical and chemical characteristics of the soils. Therefore, further investigations of these characteristics are recommended for future studies.

The results of pH and EC from the test plot and pot experiments in 2011 showed similar trends as the results of 2010. The soil pH increased almost to 9.5 compared with pH 8 of the original sandy soil. The EC values increased proportionally to the increasing SAP concentration regardless to the irrigation water quality (**Table 4.8**).

Due to the high salt concentration in the irrigation waters of AWS and AWSs the EC values of the irrigated soils were high in comparison to soils irrigated with FW, TW, AWM and AWMs. The unexpected EC results from the soil amended with 0.4% SAP and irrigated with fresh water appeared again within the results of 2011 (**Table 4.8**).

Table 4.7: Effect of irrigation water quality and SAP application on pH and electrical conductivity of the sandy soil in 2010 (25 ^{o}C, n = 3).

Irrigation water quality, polymer concentration and soil sample		pH	EC [µs/cm]	EC decrease [%][a]	EC increase [%][b]
Original sandy soil [c]		8.3	331.8	-	-
Plant hole soil from test plot experiment					
	0.0%	9.1	65.8	80	-
FW	0.2%	9.3	74.7	77	14
	0.4%	9.4	174.0	48	164
	0.0%	9.2	56.8	83	-
TW	0.2%	9.2	65.8	80	16
	0.4%	9	77.7	77	37
Rhizosphere soil from test plot experiment					
	0.0%	9.2	78.2	76	-
FW	0.2%	9.3	85.3	74	9
	0.4%	9.6	157.0	53	101
	0.0%	9.2	60.0	82	-
TW	0.2%	9.3	67.0	80	12
	0.4%	9.2	78.0	76	30

TW: Treated wastewater, FW: Fresh water, P%: polymer concentration

[a] EC decrease [%] was calculated in comparison with original sandy soil

[b] EC increase [%] was calculated in comparison with 0.0% SAP within the same type of soil sample and irrigated water

[c] Original sandy soil: Sandy soil without SAP amendment and without irrigation

Table 4.8: Effect of irrigation water quality and SAP application on pH and electrical conductivity of the sandy soil in 2011 (23 ^oC, n = 3).

Irrigation water quality, polymer concentration and soil sample		pH	EC [µs/cm]	EC decrease [%][a]	EC increase [%][b]
Original sandy soil[c]		8	279	-	-
Plant hole soils from test plot experiment					
	0.0%	8.8	87	69	-
FW	0.2%	8.9	96	66	9
	0.4%	9.9	248	11	65
	0.0%	9	99	64	-
TW	0.2%	8.8	111	60	11
	0.4%	9.8	169	39	41
	0.0%	9.5	205	27	-
AWS	0.2%	9.2	217	22	6
	0.4%	9.6	242	13	40
	0.0%	9.3	100	64	-
AWM	0.2%	9.8	101	64	1
	0.4%	10.2	191	32	48
Plant hole soils from pot experiment					
	0.0%	9.5	147	47	-
AWMs	0.2%	9.5	192	31	23
	0.4%	10.5	263	6	60
	0.0%	9.2	585	-110[d]	-
AWSs	0.2%	9.8	646	-132	9
	0.4%	10	661	-137	11

TW: Treated wastewater, FW: Fresh water, P%: polymer concentration

[a] EC decrease [%] was calculated in comparison with original sandy soil

[b] EC increase [%] was calculated in comparison with 0.0% SAP within the same type of soil sample and irrigated water

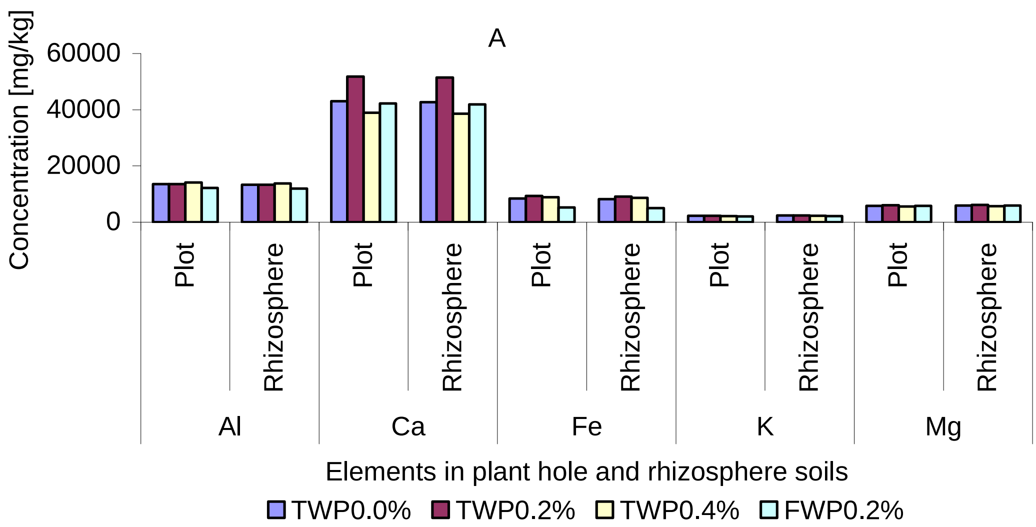
[c] Original sandy soil: Sandy soil without SAP amendment and without irrigation

[d] The results with minus, means increased occurrence, but not decrease

4.2.5 Optimization of soil sampling and isotherm equation for soil analysis

4.2.5.1 Type of samples collected from the soil

The comparison between the plant hole and rhizosphere soil samples collected randomly from 4 test plots (TWP0.0%, TWP0.2%, TWP0.4% and FWP0.2%) showed an almost equal concentration of each element in both samples **(Figure 4.4)**. For that reason, in the field experiments (test plot and pot experiments) one representative sample was prepared by mixing the plant hole and rhizosphere soils to carry out the element analysis.



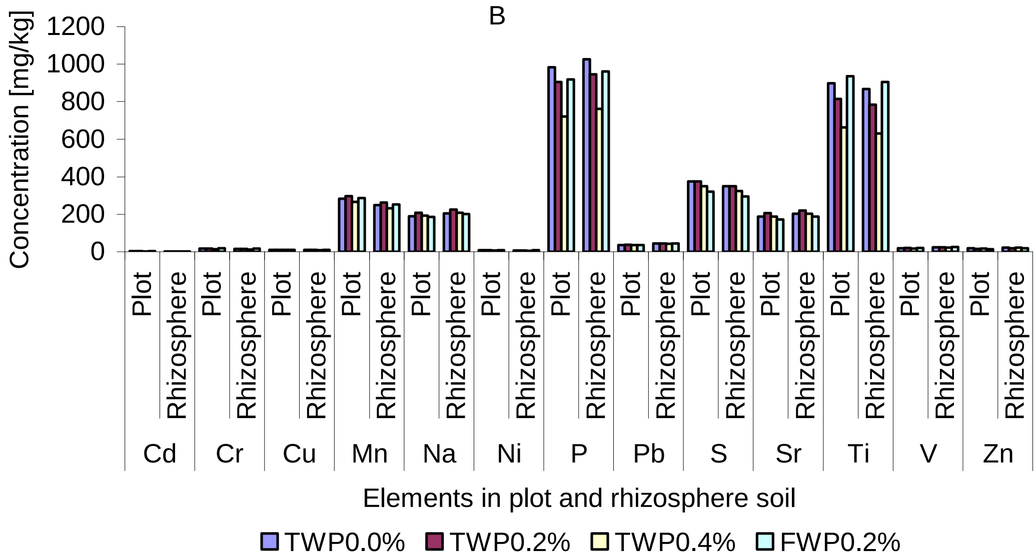


Figure 4.4: Element concentrations in plant hole and rhizosphere soil samples; **A:** Al, Ca, Fe, K and Mg. **B:** Cd, Cr, Cu, Mn, Na, Ni, P, Pb, S, Sr, Ti, V and Zn.

4.2.5.2 Effect of soil grain size on element concentration

The soil samples sieved by < 125 µm contained 2-3 times element concentration of that found in < 2 mm sieved samples. This was expected, because fine soil particles have a higher surface area than that of coarse particles. The polymer granules passed the sieve size < 2 mm but not the sieve size < 125 µm. Therefore, the sieve size of < 2 mm was adopted in all element analyses within this study **(Figure 4.5)**.

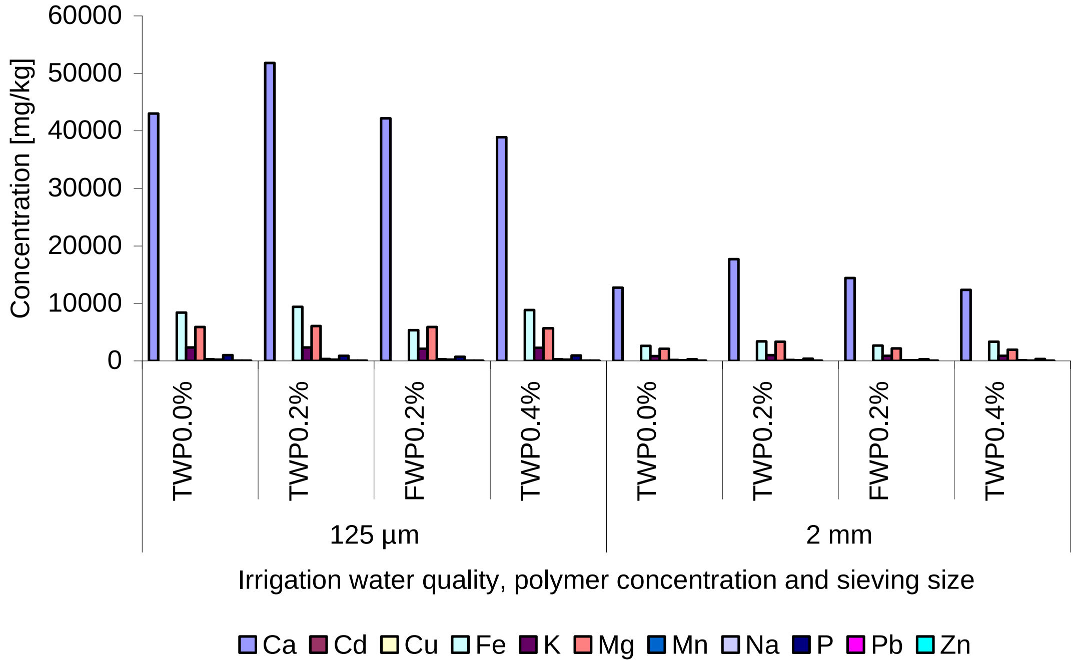


Figure 4.5: Effect of the sieving size of sandy soil-SAP mixture on the elements content

4.2.5.3 Freundlich and Langmuir isotherms for Cd adsorption

Cadmium is often detected in industrial wastewaters, which originate from metal plating, smelting, battery manufacture, petroleum refining, pesticides, pigment manufactures, photographic industries, etc. Cadmium from these sources is dissolved in the water and finds its way into the environment and human system. Therefore, cadmium was chosen as model for heavy metal adsorption by SAP (section 4.2.6) and for metal uptake by bacteria (section 4.4.6).

Freundlich and Langmuir adsorption isotherms were used to model the adsorption data of Cd on sandy soil and sandy soil amended with 0.4% SAP (w/w). The adsorption isotherms fitted well to both models. The Langmuir model gave the better fit of data, as was evidenced from the higher value of R^2 of 0.9992 and 0.9834 for the sandy soil and sandy soil amended with 0.4% SAP, respectively. The R^2 of the Freundlich model yield 0.9438 and 0.9619 for the sandy soil and sandy soil amended with 0.4% SAP, respectively (**Figure 4.6 and Figure 4.7**). A comparison between Freundlich and Langmuir isotherms for adsorption of methylene blue by agrowaste derived activated carbon was carried out by Okeola and Odebunmi (2010). They found a R^2 of the Langmuir model at 0.9999, which fitted their data better than the Freundlich model with a R^2 0.9922. Zheng et al. (2010) studied the adsorption behavior of Cu from aqueous solutions onto starch-g-poly (acrylic acid/sodium humate hydrogels). They found the Cu adsorption data fitted better by Langmuir equation (R^2 = 0.9995) than by Freundlich equation (R^2 = 0.8199). Therefore, the Langmuir equation was used to evaluate the adsorption results in the present study as reason of R^2 higher than that of Freundlich.

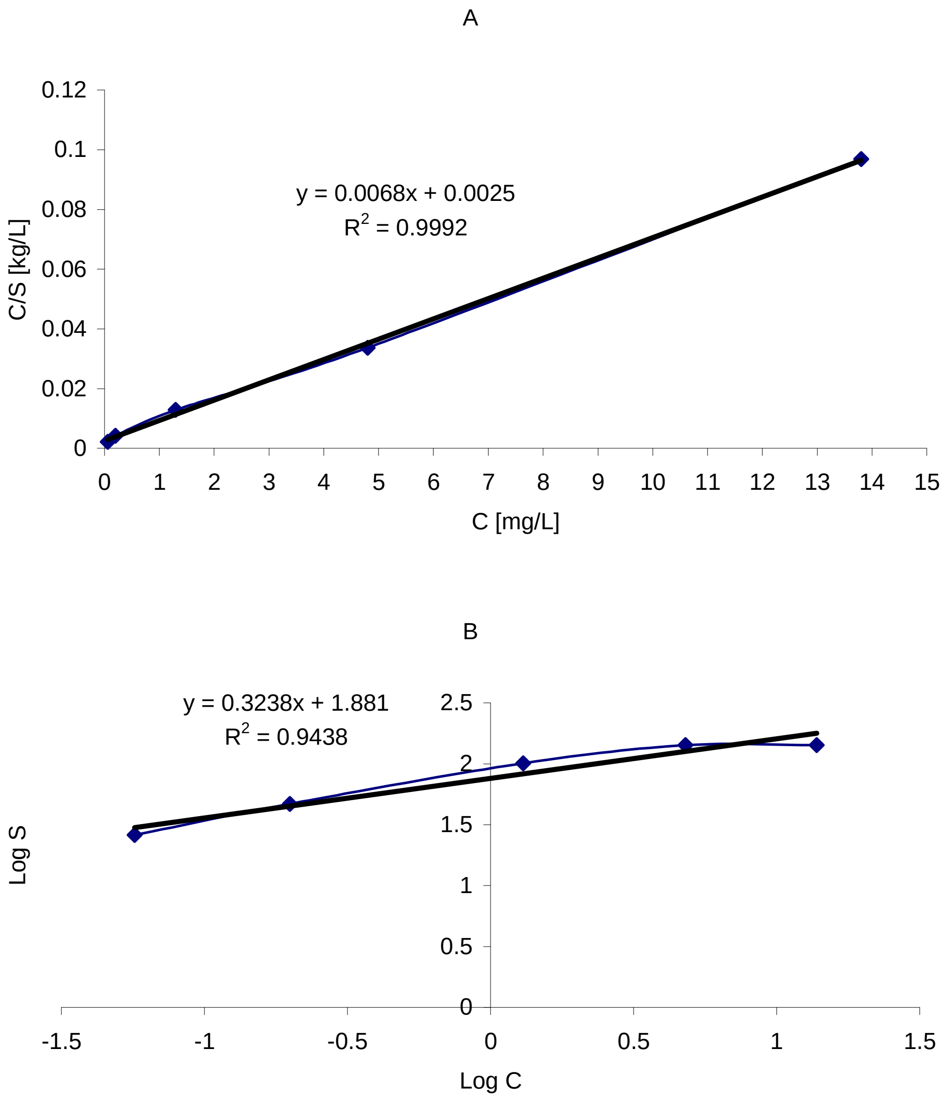


Figure 4.6: Experimental data points determined for the adsorption of Cd on sandy soil **A:** Langmuir equation **B:** Freundlich equation **S**: Mass of sandy soil (kg); **C**: Equilibrium concentration

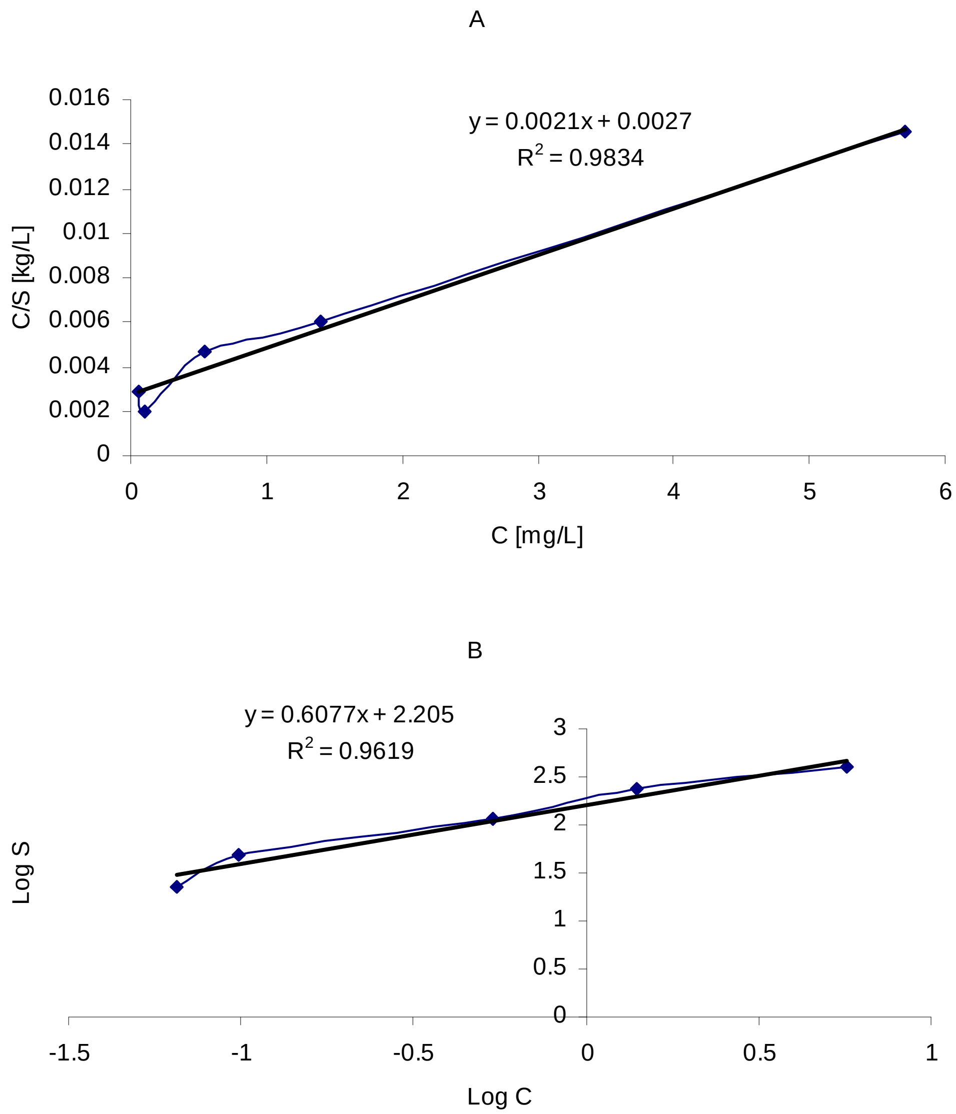


Figure 4.7: Experimental data points determined for the adsorption of Cd on sandy soil amended with 0.4% SAP (w/w) **A:** Langmuir equation **B:** Freundlich equation **S**: Mass of sandy soil (kg); **C**: Equilibrium concentration

4.2.6 Sorption experiments

4.2.6.1 Adsorption

The adsorption experiments were carried out using soil solutions and deionized water additionally spiked with cadmium. For data analysis, the Langmuir equation was applied. The sandy soil amended with 0.4% SAP concentration showed an ability to adsorb cadmium 37 times higher than sandy soil without SAP amendment when cadmium was applied in soil solution. But, when the cadmium was applied in deionized water, the sandy soil with 0.4% SAP concentration showed an ability to adsorb cadmium 3 times higher than sandy soil without SAP amendment (**Table 4.9**).

Table 4.9: Cadmium maximum adsorption by sandy soil with and without SAP amendment

	sandy soil solution[1] (pH = 9)		pure solution[2] (pH = 7)	
Sample ID	0.4% SAP[3]	without SAP	0.4% SAP	without SAP
Adsorption [mg/kg]	294	8	476	147

[1] Sandy soil solution: Cd dissolved in soil solution

[2] Pure solution: Cd dissolved in deionized water

[3] SAP: Sandy soil amended with 0.4% super absorbent polymer

As expected, the sandy soil amended with 0.4% SAP showed a much higher Cd adsorption compared with the sandy soil without SAP amendments. This meets the results of Guilherme et al. (2007). They found the hydrogel made from an anionic polysaccharide copolymerized with acrylic acid and acrylamide exhibited capacity for the absorption of Pb^{2+} and Cu^{2+}. It was 73% and 82% in water and in saline water it was 64% and 77%, respectively. Also other authors, i.e., Zohuriaan-Mehr et al. (2010) and Hüttermann et al. (2009) confirmed the high ability of superabsorbent polymers to bind heavy metals.

4.2.6.2 Desorption

The Cd desorption from the sandy soil without SAP amendment is directly proportional to the Cd concentrations. The desorption/adsorption percentage was 21% at 0.01 mmol Cd and increased proportionally to 52% at 0.1 mmol Cd when prepared in deionized water. In soil solution, the desorption/adsorption percentage was 17% at 0.01 mmol Cd. At 0.1 mmol Cd it increases to 56%. The desorption/adsorption percentage of Cd from the sandy soil amended with 0.4% SAP (w/w) was constant regardless to the Cd concentration. The percentages are 25 and 15% for the soil solution and deionized water, respectively **(Figure 4.8)**.

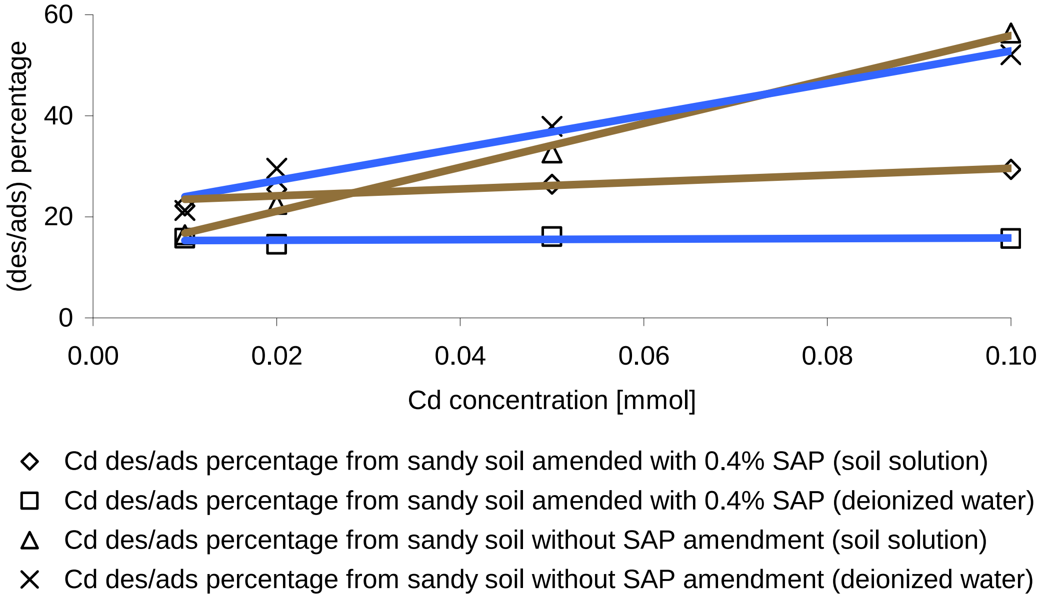


Figure 4.8: Cd desorption/adsorption percentages from Jordanian sandy soil and Jordanian sandy soil amended with 0.4% SAP.

The experiments proved a high retention potential for adsorbed cadmium within the sandy soil amended with 0.4% SAP in comparison with the sandy soil without SAP amendment. Prasad and Freitas (1999) mentioned that hydrogels increased the ability of plants to grow in areas contaminated with heavy metals. They prevented, i.e., the uptake of excessive amounts of lead. In addition to the protection against different stress factors (water, salt, and soil acidity) SAP-soil mixtures can protect plants also against heavy metal stress (Hüttermann et al., 2009; Hüttermann and Zomorrodi, 1999). The ability of SAP to decrease the metal stress for the plant by adsorbing toxic metals from the available water was checked in this study in the irrigation experiments with water, which was contaminated artificially with high metal concentrations.

4.2.7 Chemical element analysis

The homogeneity of results of the element analysis in soil samples was checked by analyzing 4 plant hole soil samples collected from the same test plot. The results of element concentrations proved the homogeneity of the results. The concentrations of each element were almost equal in the 4 soil samples (**Figure A1**, see **appendix**).

A statistical evaluation of element concentrations in soil samples from the test plot experiment in 2010 showed no differences (**Figure 4.9**). Furthermore, no differences between original soil and SAP amended soil were found. Since the chemical composition of fresh water and treated wastewater were similar to a large extend, reflecting the low contamination of the wastewater of Mutah University campus, it was necessary to prepare artificially contaminated wastewater in order to check for salt and heavy metal stress.

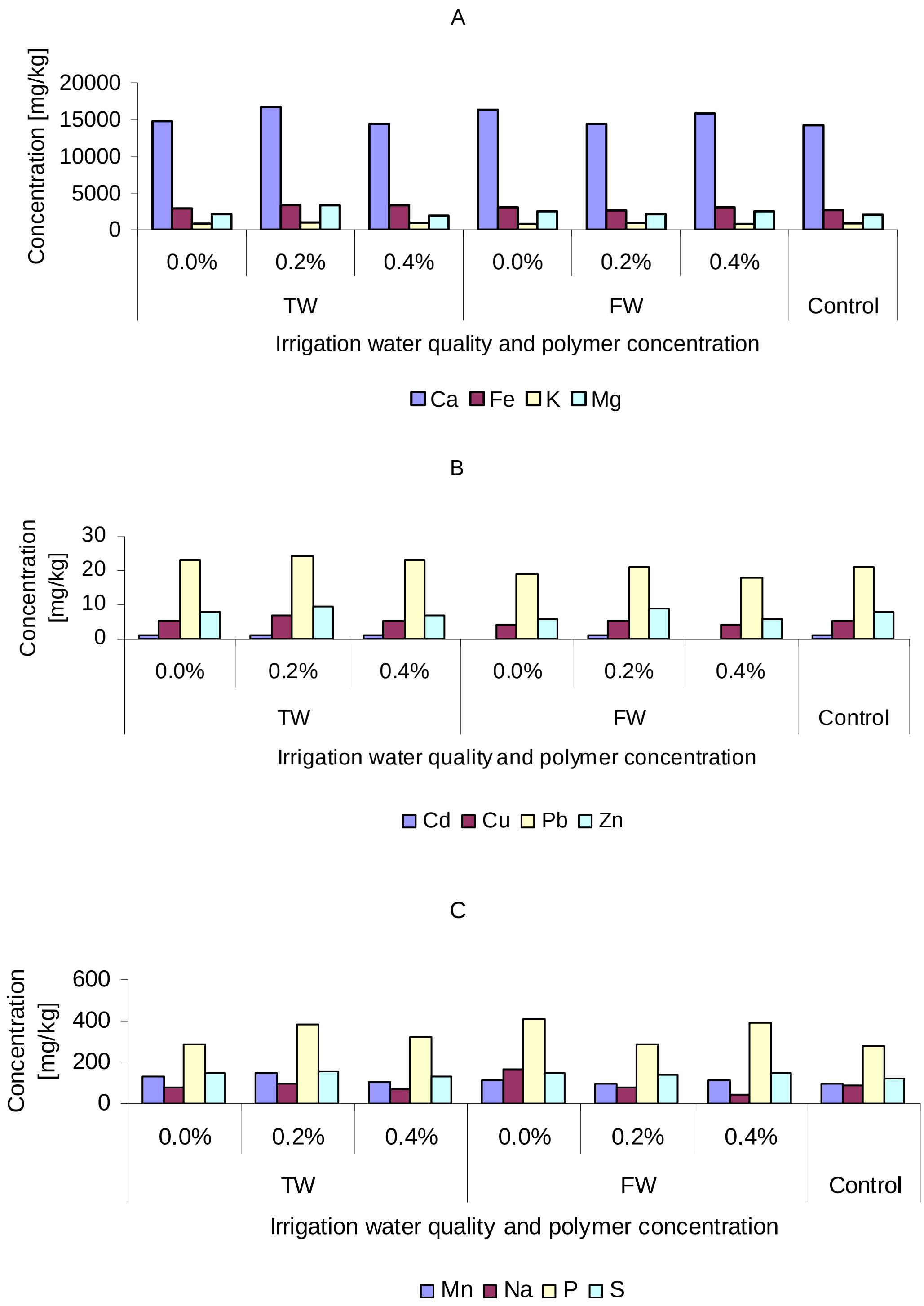


Figure 4.9: Irrigation experiment in 2010: Effect of irrigation water quality and polymer concentration on the element concentrations in soil; **A:** Ca, Fe, K and Mg. **B:** Cd, Cu, Pb, and Zn. **C:** Mn, Na, P and S.

A comparison of the analysis of soil samples between the findings of test plot experiments in 2011 and 2010 (**Figure 4.9, Figure 4.10**) showed regular trend between the soil samples regardless of the SAP concentration and irrigation water quality. As an exception, the concentration of Na appeared higher in the soil samples irrigated with AWS and AWSs. This was expected due to the high concentration of Na in AWS and AWSs.

In spite of irrigation with AWM and AWMs, containing raised concentrations of Cu and Zn, the soil analysis did not show any difference in these element concentrations. Pichtel and Bradway (2008) mentioned, at soil pH values greater than 7, Cd can precipitate as $Cd(OH)_2$ or by forming minerals such as otavite ($CdCO_3$) and monteponite (CdO). Numerous researchers reported that calcium carbonate may be the dominant sorbent for a variety of metals in alkaline environments, involving reactions with $CaCO_3$ surfaces (Torri and Correa, 2012). Stacey (2007) reported that trace element deficiencies are commonly encountered on alkaline soils due to their high metal adsorption and fixation capacities. All of the trace metal precipitate under alkaline conditions to form hydroxides, oxides, carbonates, and phosphates (McLean and Bledsoe, 1992). Lennartz and Braunmiller (2012) carried out column experiments to measure the copper breakthrough using the same Jordanian sandy soil used in this study with and without SAP amendments. They found out that copper was not percolated through the column; it precipitated at the top few centimeters of the column. The copper concentration was 1671, 495 and < 0.2 mg/kg within the layers of 0-1, 1-2 and 2-3 cm, respectively. Therefore, the results from the present study were interpreted to be due to alkaline pH of the soil which was 8. It is assumed that the metals were precipitated in the upper layer of soil while the soil samples were collected from the root zone. However, an additional sampling has to validate this assumption.

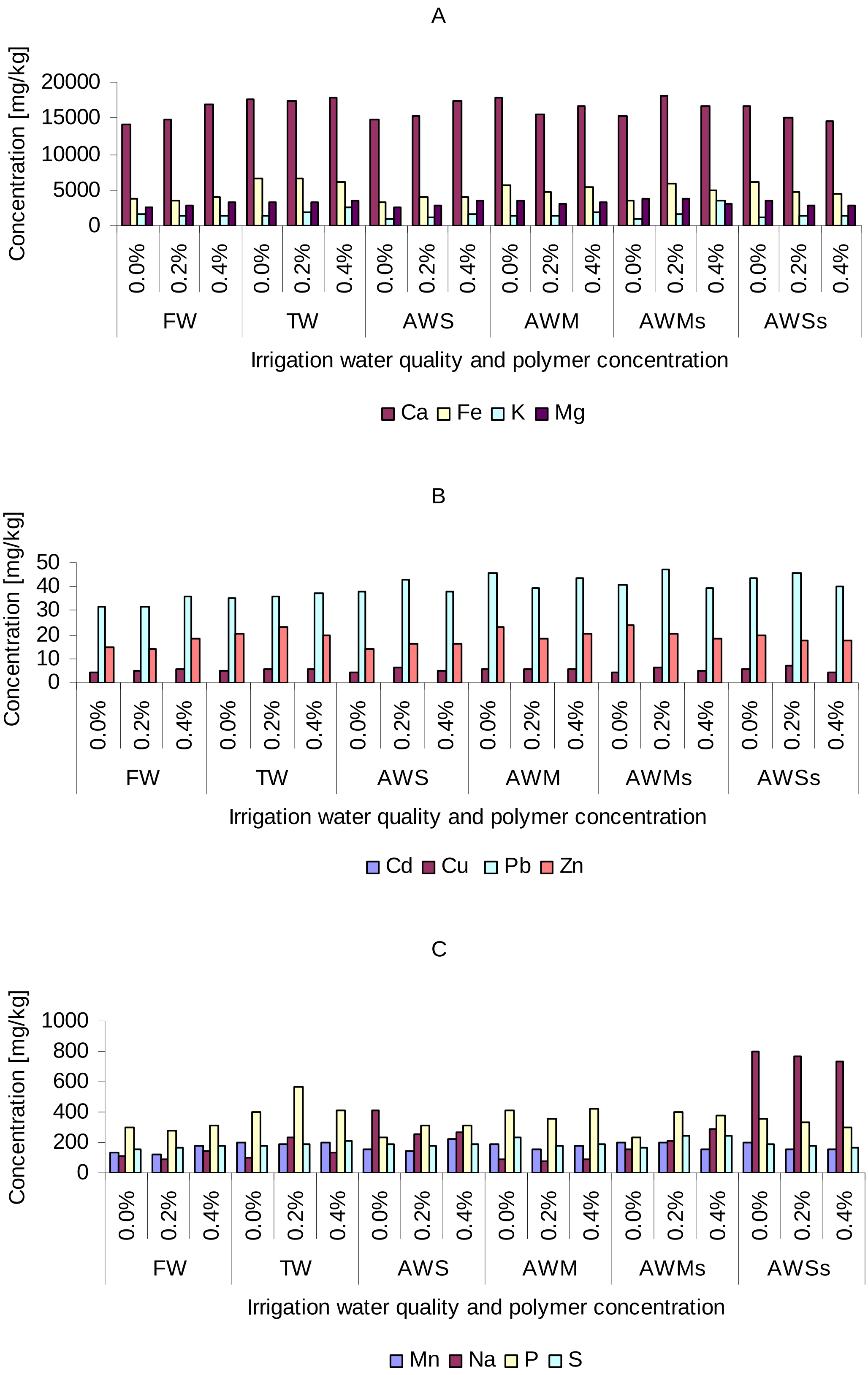


Figure 4.10: Irrigation experiment in 2011: Effect of irrigation water quality and polymer concentration on the element concentrations in soil; **A:** Ca, Fe, K and Mg. **B:** Cd, Cu, Pb, and Zn. **C:** Na, P and S.

4.2.8 Kjeldahl nitrogen

Kjeldahl nitrogen was determined during the test plot experiment in 2010 for the plant hole and rhizosphere soils. The results showed a very slight increase of nitrogen in the plant hole soil with increasing amount of SAP. No differences in nitrogen content were found in the rhizosphere soils regardless of the SAP concentration and irrigation water quality (**Table 4.10**).

Syvertsen and Dunlop (2004) mentioned that N retention in soil increased slightly when the soil was amended with increasing portions of acrylamide/acrylate copolymer (PAM). However, an effect on plant growth, water use, and N uptake was indiscernible in comparison with the control plants. Contrary, after the soil was amended with a cross-linked copolymer agronomic gel (AGRO), the seedling growth, plant water use, and uptake of N increased from 11 to 45% above that of the control (Syvertsen and Dunlop, 2004).

Al-Absi and Mohawesh (2009) reported a total amount of nitrogen in the Jordanian sandy clay loam soil between 1.5 and 2.2 g/kg, which is considered optimal for most crops. The Jordanian sandy soil used in this study was poor in nitrogen content (0.05 g/kg). In order to maintain the original conditions, the studies were carried out without fertilizer application, which means a shortage of nitrogen resource. However, the irrigation water contained nitrate as a source of nitrogen. The amount of this nitrogen could be taken up by the plant or leached through the soil. Moreover, nitrogen occurs mainly as NO_3^- and less amounts as NH_4^+. The SAP is negatively charged, therefore, it does not retain the NO_3^-, following, no influence on nitrogen retention. Syvertsen and Dunlop (2004) mentioned linear acrylamide/acrylate copolymer (PAM) amended plants leached 13% of the N applied, which did not differ from that of the untreated control plants. Opposite findings observed by the same author, when a cross-linked copolymer agronomic gel (AGRO) was used only 6% of the total applied N was leached, which was about half that from the untreated control plants. Furthermore, the studies proved that the polymer type as well as the application method plays an important role on the efficiency of hydrogels.

Analogous to these findings, the present studies did not show any or only very slight differences in the nitrogen content in all samples regardless of the concentration of SAP and irrigation water quality. Therefore, the nitrogen was not analyzed in soil samples within the test plot series in 2011 in order to reduce the high number of samples under analysis without losses of relevant information.

Table 4.10: Total nitrogen in plant hole and rhizosphere soils amended with different SAP concentrations and irrigated with treated wastewater and fresh water (n = 3)

Irrigation water quality	Polymer concentration	N_{total} in rhizosphere soil [g/kg]	N_{total} in plant hole soil [g/kg]
Fresh water	0.0 %	0.10	0.06
	0.2 %	0.04	0.08
	0.4 %	0.06	0.09
Treated wastewater	0.0 %	0.11	0.04
	0.2 %	0.10	0.07
	0.4 %	0.09	0.08

4.2.9 Total organic carbon

TOC was determined for the plant hole and rhizosphere soil samples. The studies were performed by maintaining the original soil properties and, therefore, no organic fertilizers were amended to the soil, and the SAP was applied in very low concentration. Therefore, the differences in TOC content between all soil samples remained under the detectable discrimination limit, regardless of the SAP concentration and irrigation water quality. For that reason, this TOC was not analyzed within the test plot experiment in 2011. Different total organic content were found between rhizosphere and plant hole soil samples. However, those were probably caused by remaining root residues in the rhizosphere soil samples (**Table 4.11**).

Table 4.11: Total organic carbon in rhizosphere and plant hole soils amended with different SAP concentrations and irrigated with fresh water and treated wastewater (n = 3)

Irrigation water quality	Polymer concentration	TOC [ds % ± SD]	
		Plant hole soil	Rhizosphere soil
Fresh water	0.0 %	0.06 ± 0.01	0.14 ± 0.01
	0.2 %	0.10 ± 0.01	0.14 ± 0.02
	0.4 %	0.14 ± 0.01	0.18 ± 0.02
Treated wastewater	0.0 %	0.05 ± 0.01	0.13 ± 0.02
	0.2 %	0.10 ± 0.01	0.17 ± 0.02
	0.4 %	0.08 ± 0.01	0.18 ± 0.01

4.2.10 Microbial activity

Substrate induced respiration was determined for evaluating the effects of SAP application and irrigation measures on the microbial activity in soil.

The results did not show any relevant differences in the microbial activity between all samples, regardless of the SAP concentration or irrigation water quality (**Table 4.12**). Popelářová et al. (2008) measured as an indicator for soil respiration the CO_2 production by microflora in arable soils by means of interferometry. They found the average values 0.45, 4.25, and 9.5 mg CO_2/h per 100 g dry soil in the control, soil amended with glucose as carbon source, and soil amended with glucose and ammonium sulphate as carbon and nitrogen sources, respectively.

The results of Kjeldahl nitrogen (section 4.2.8) and total organic carbon (section 4.2.9) illustrated that the Jordanian sandy soil used within this study was poor in nitrogen and carbon content. Moreover, this experiment was carried out without fertilizer application. Therefore, the missing differences of respiration in this study are interpreted to be due to the shortage in nitrogen and carbon resources in the used soil. Based on these findings, further tests on microbial activity were excluded from the test plot experiment in 2011.

Table 4.12: Substrate induced respiration [mg O_2/(kg h)] in plant hole soil samples from test plot and pot experiments in 2010 (n = 3)

Irrigation water quality	Polymer concentration	Plant hole soil from test plot experiment	Plant hole soil from pot experiment
Fresh water	0.0 %	1.8	1.8
	0.2 %	2.7	3.6
	0.4 %	1.8	1.8
Treated wastewater	0.0 %	2.7	3.6
	0.2 %	2.7	3.8
	0.4 %	1.8	1.8

4.3 Plant study

4.3.1 Eggplants growth parameters and biomass

4.3.1.1 Growth rate of eggplants

The rate of growth parameters in the test plot and pot experiments of the years 2010 and 2011 were monitored during the vegetation period of 12 weeks. The results from the year 2010 (**Figures 4.11 to 4.13**) showed the highest growth rate for a SAP concentration of 0.2% in both test plot and pot experiments regardless of the irrigation water quality. The growth rate was determined by stem diameter, plant height, and number of leaves. Dorraji et al. (2010) reported the highest aerial and root biomass for the application of Superab A200, a copolymer derived from acrylamide, acrylic acid, and potassium acrylate, at the concentrations of 0.6% and 0.2% in loamy sand soil and in sandy clay loam soil, respectively. Hüttermann et al. (1999) reported an increase in root and plant growth for Aleppo Pine at 0.4% hydrophilic polymer application. Al-Harbi et al. (1999) reported an increase in cucumber growth by using 0.3% hydrophilic polymer application in a loamy sand soil. Based on the results from the present study and the findings of other authors, it can be interpreted that the polymer efficiency on the plant growth varies in dependence of the soils as well as of the plant species cultivated.

The pot results showed lower plant growth rates compared with the test plot experiments. At the end of the vegetation period, the growth rate of the stem diameter of the eggplants grown in pots amended with 0, 0.2 and 0.4% SAP and irrigated with fresh water were only 50, 48 and 28% of those grown in the test plots, respectively. For the plant height, it was about 40% (38/ 41/ 38%), and about 35% (30/ 36/ 35%) for the number of leaves (**Table 4.13**). Irrigation of pot plants with treated wastewater resulted in a similar behavior. Due to the nutrients contained in the wastewater the growth reduction was smaller in comparison with fresh water irrigation (**Table 4.13**). These results were probably caused by the limited volume of the pots that affected particularly the plant root growth. Similar results were found by Ray and Sinclair (1998), who observed a large effect of the pot size on plant growth. They found that maize grown in 2 L pots was 44% of the plants grown in the 16 L, and soybean plants grown in the 4 L pots were 45% of those grown in 16 L pots. These findings might be caused by large influence of the water amount available for transpiration. They found the total transpirable soil water corresponded closely with the volume of the pot. Other authors reported, the pot size affects a number of physiological processes including nutrient efficiency (Huang et al., 1996) and photosynthesis rates (Arp, 1991). The mechanisms, which prevent plant growth in general due to restricted root growth, are unknown (Carmi, 1993).

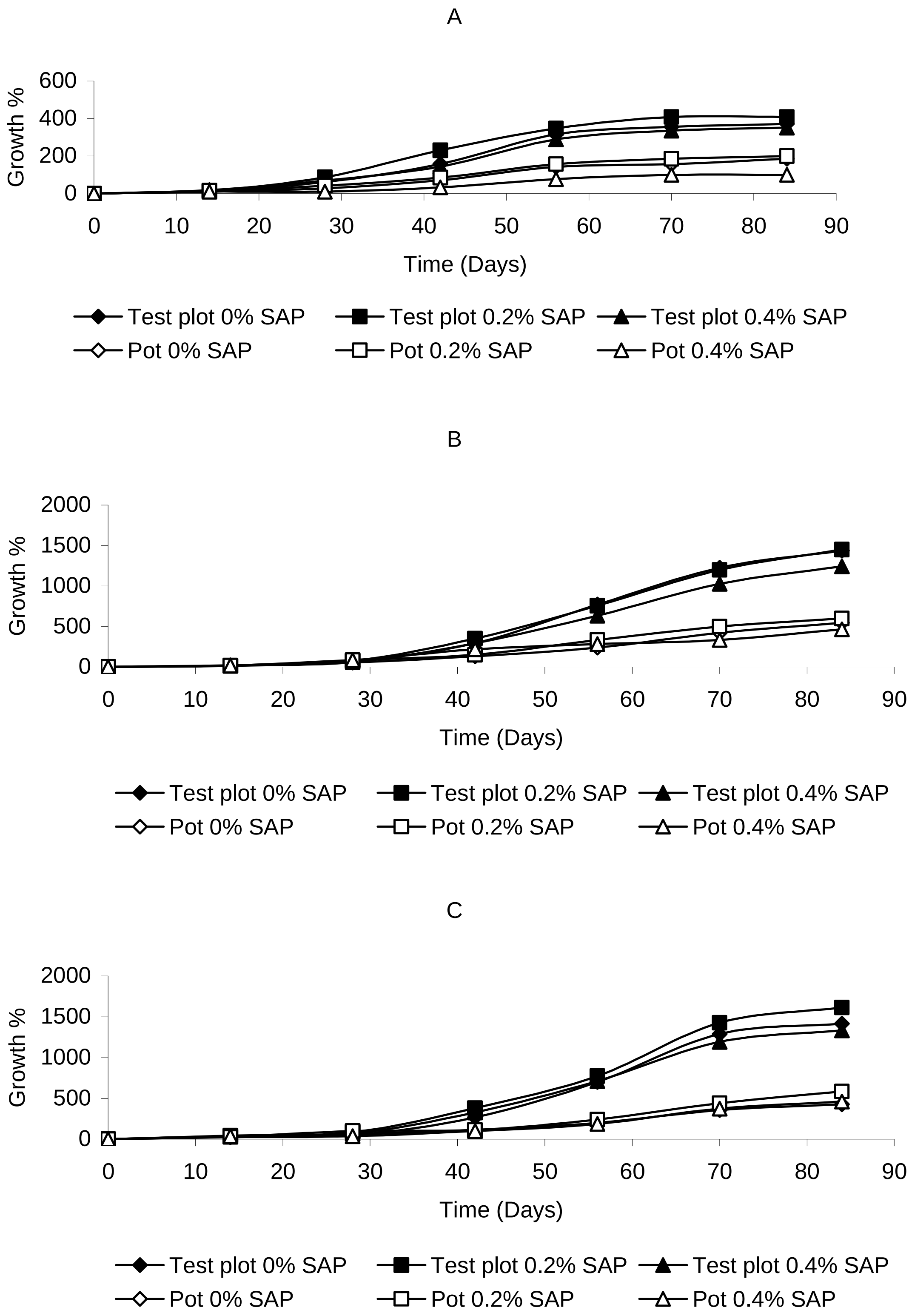


Figure 4.11: Growth rate for eggplants grown in test plot and pot experiments in 2010 irrigated with fresh water; **A:** Stem diameter, **B:** Plant height **C:** Number of leaves

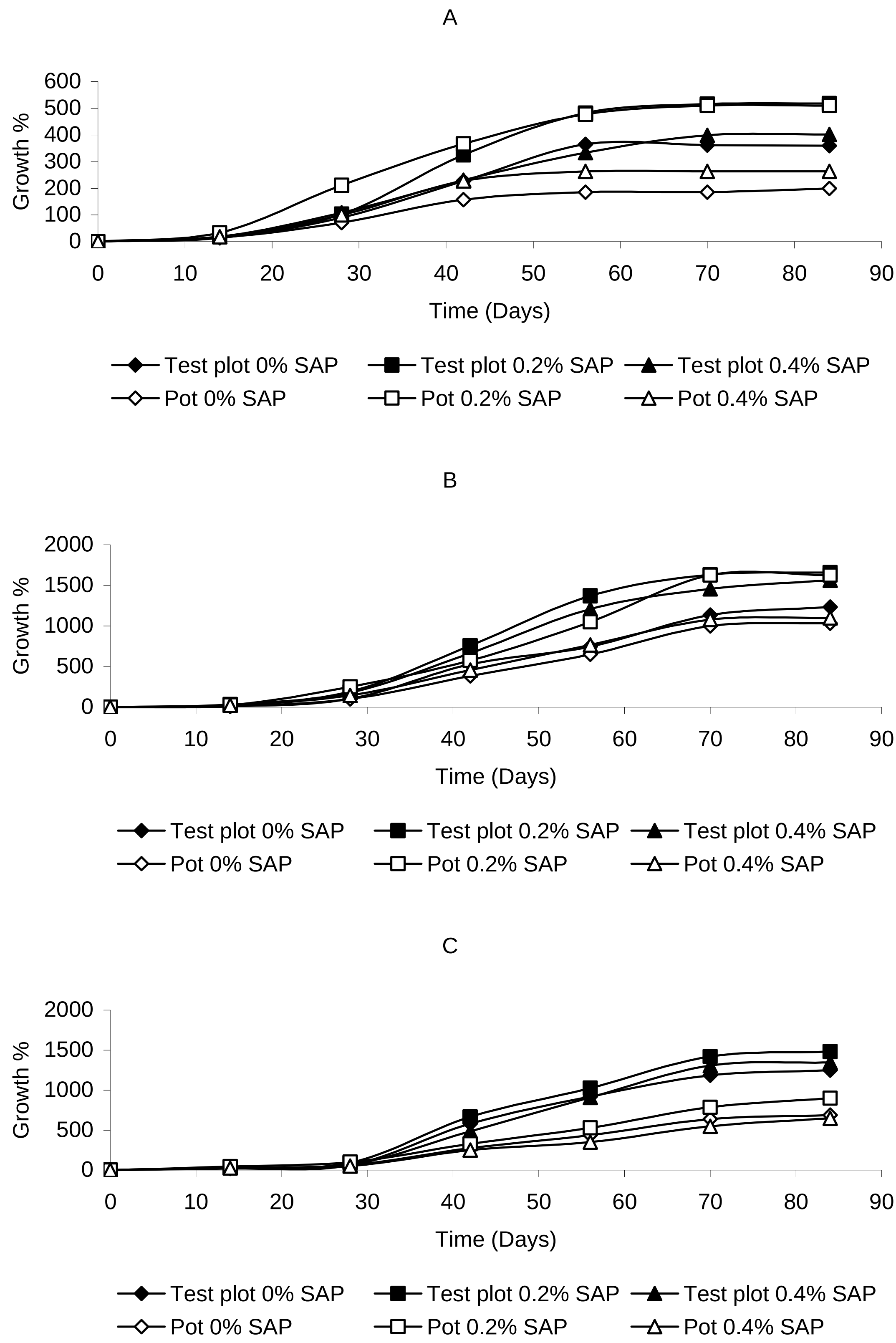


Figure 4.12: Growth rate for eggplants grown in test plot and pot experiments in 2010 irrigated with treated wastewater; **A:** Stem diameter, **B:** Plant height **C:** Number of leaves

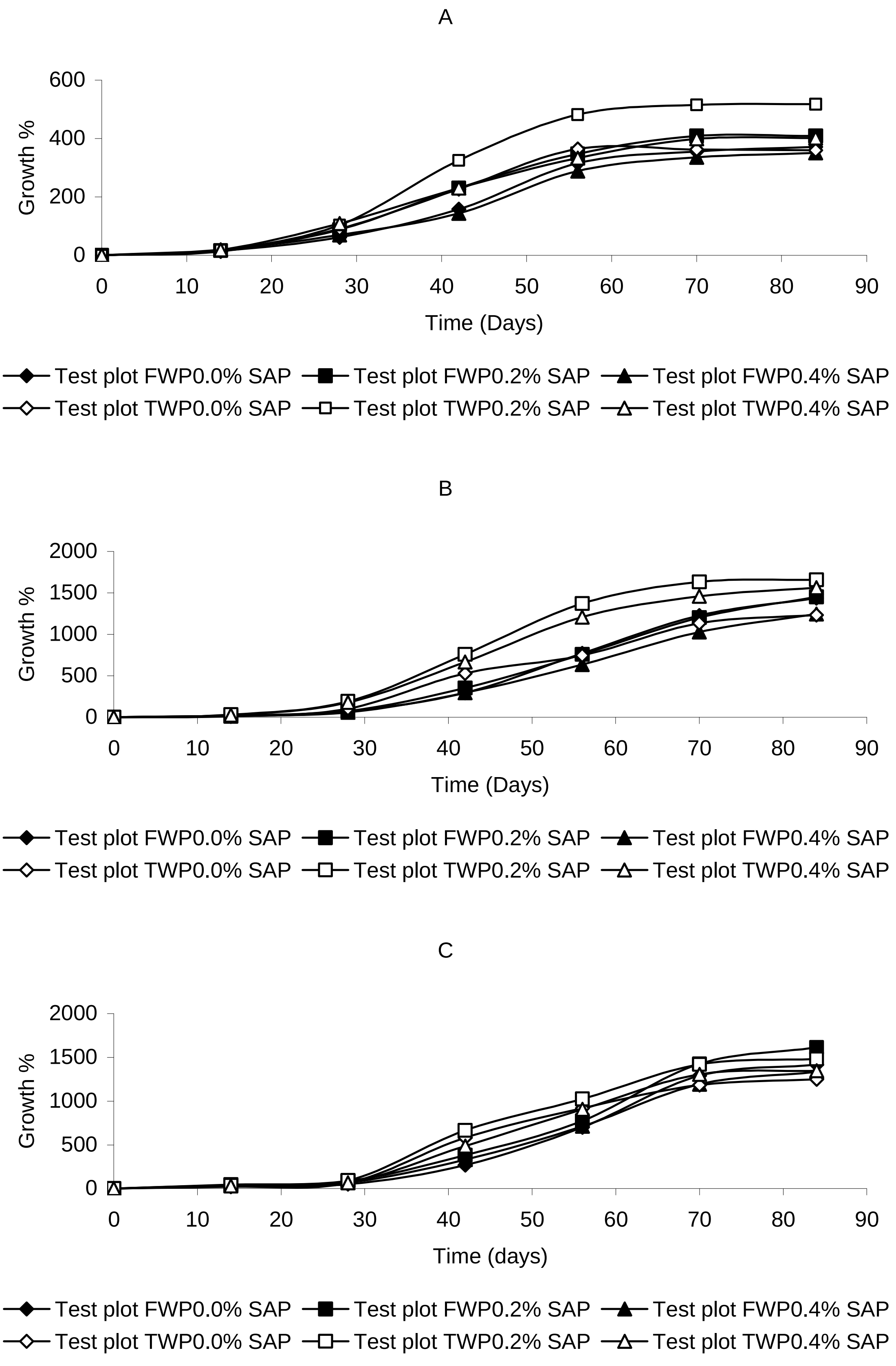


Figure 4.13: Effect of irrigation water quality on the growth rate of eggplants grown in test plot experiment in 2010 amended with different concentrations of SAP; **A:** Stem diameter, **B:** Plant height **C:** Number of leaves

Table 4.13: Growth percentage for eggplants grown in pots in comparison to those grown in test plots under same conditions of irrigation water quality and polymer concentration at the end of vegetation period

	Irrigation water quality and polymer concentration					
	Fresh water			Treated wastewater		
	0.0%	0.2%	0.4%	0.0%	0.2%	0.4%
Stem diameter [%]	50	48	28	56	98	66
Plant height [%]	38	41	38	84	98	70
Number of leaves [%]	30	36	35	55	61	48

The growth rate results from the year 2011 showed similar trends as already found in the year 2010. The highest growth rate was indicated by stem diameter and plant height occurred at a SAP concentration of 0.2% in both test plot and pot experiments regardless of irrigation water quality (**Figures 4.14 to 4.19**).

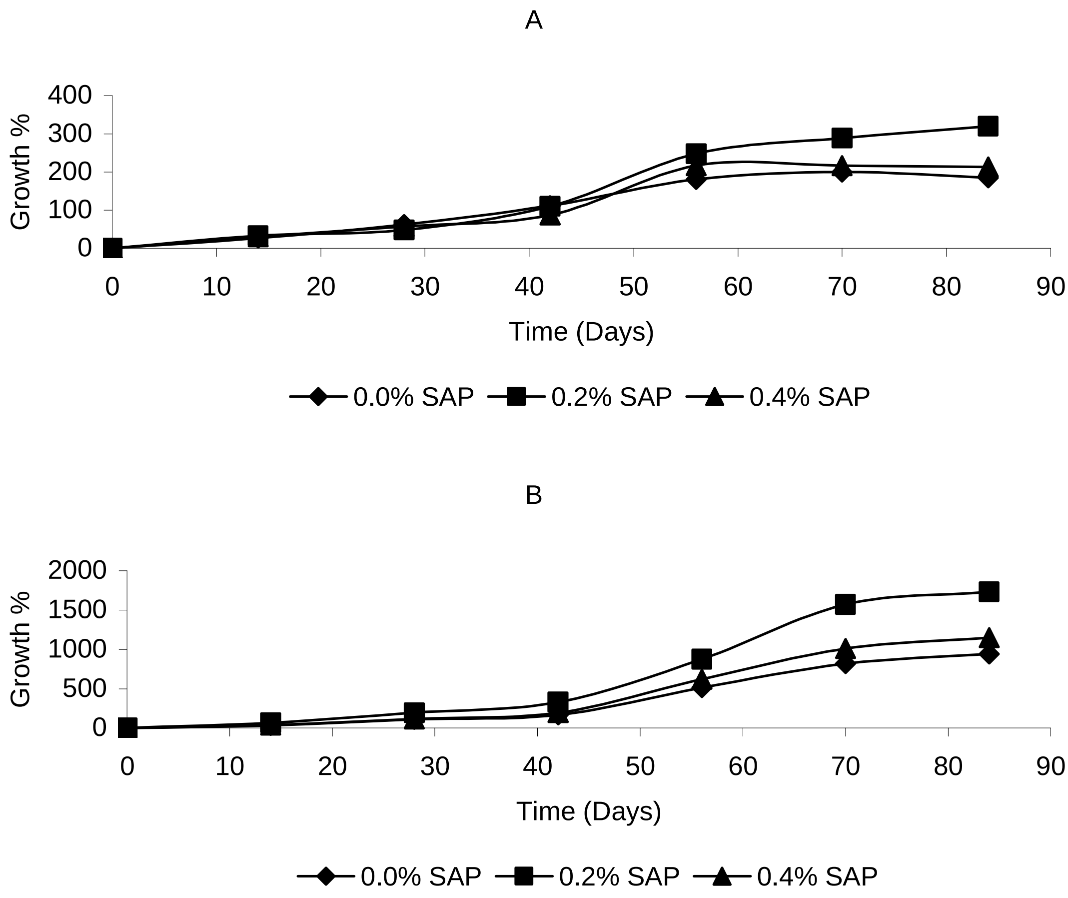


Figure 4.14: Growth rate of eggplants grown in test plot experiment and irrigated with fresh water; **A:** Stem diameter, **B:** Plant height

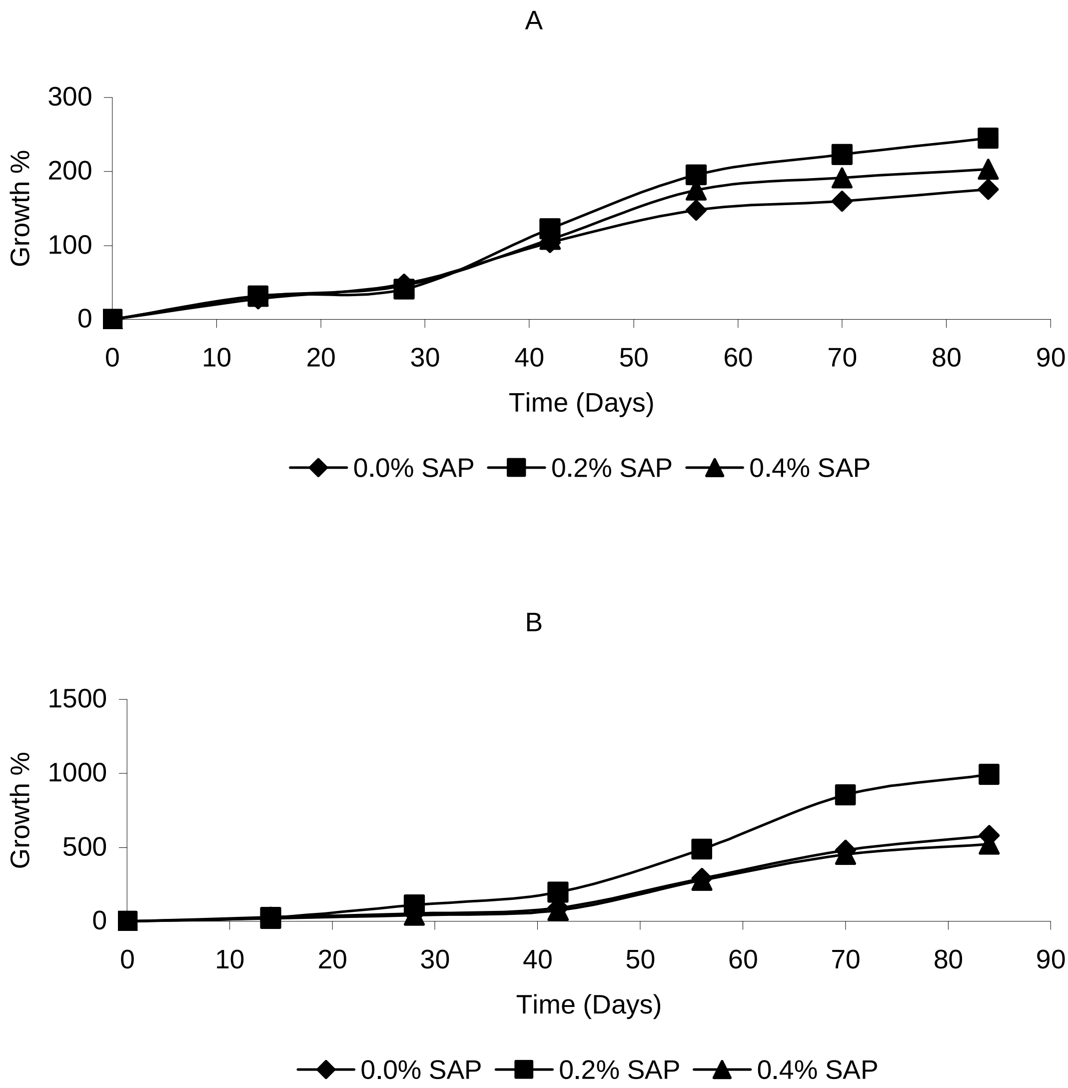


Figure 4.15: Growth rate of eggplants grown in test plot experiment and irrigated with treated wastewater; **A:** Stem diameter, **B:** Plant height

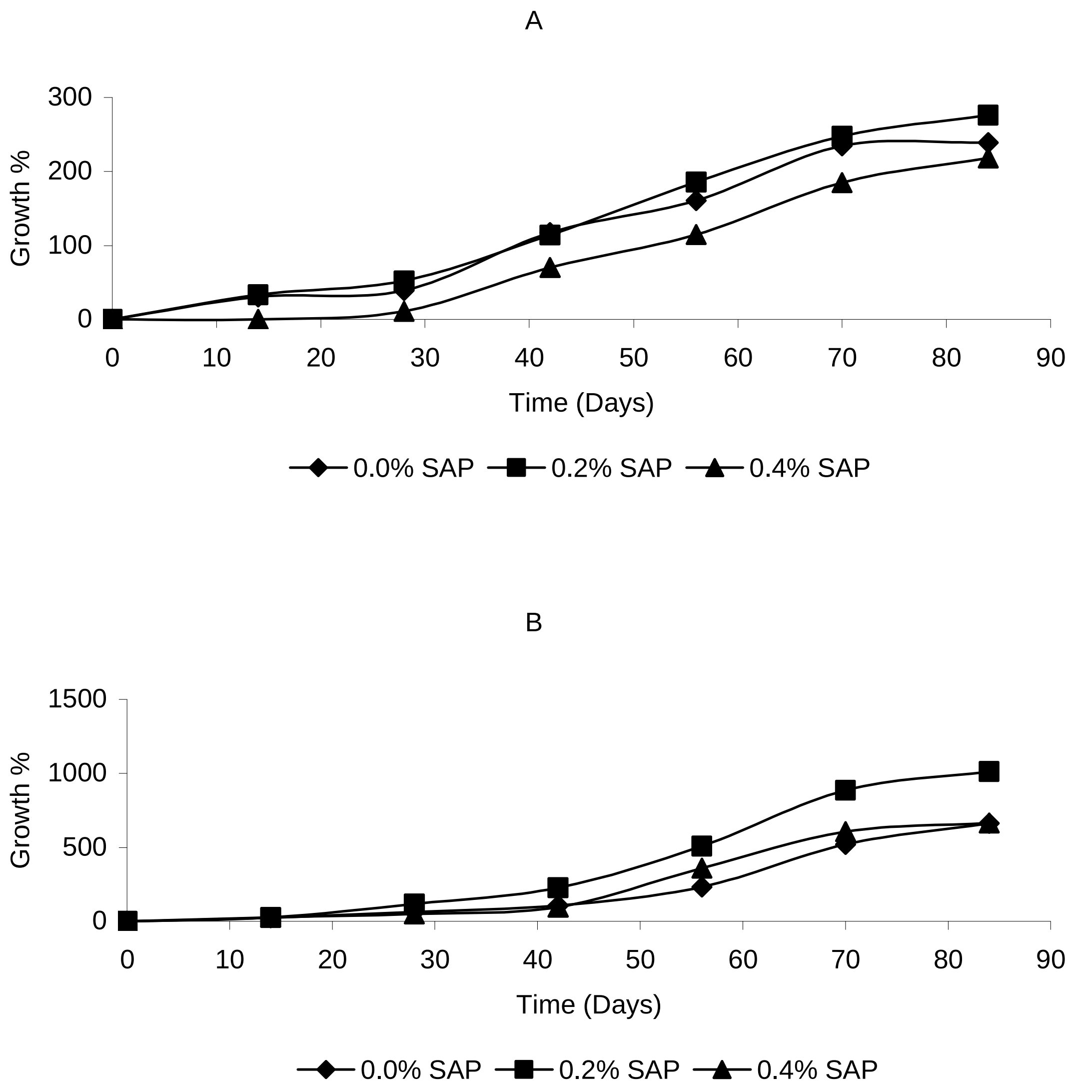


Figure 4.16: Growth rate of eggplants grown in test plot experiment and irrigated with artificial wastewater with salt within threshold value (AWS); **A:** Stem diameter, **B:** Plant height

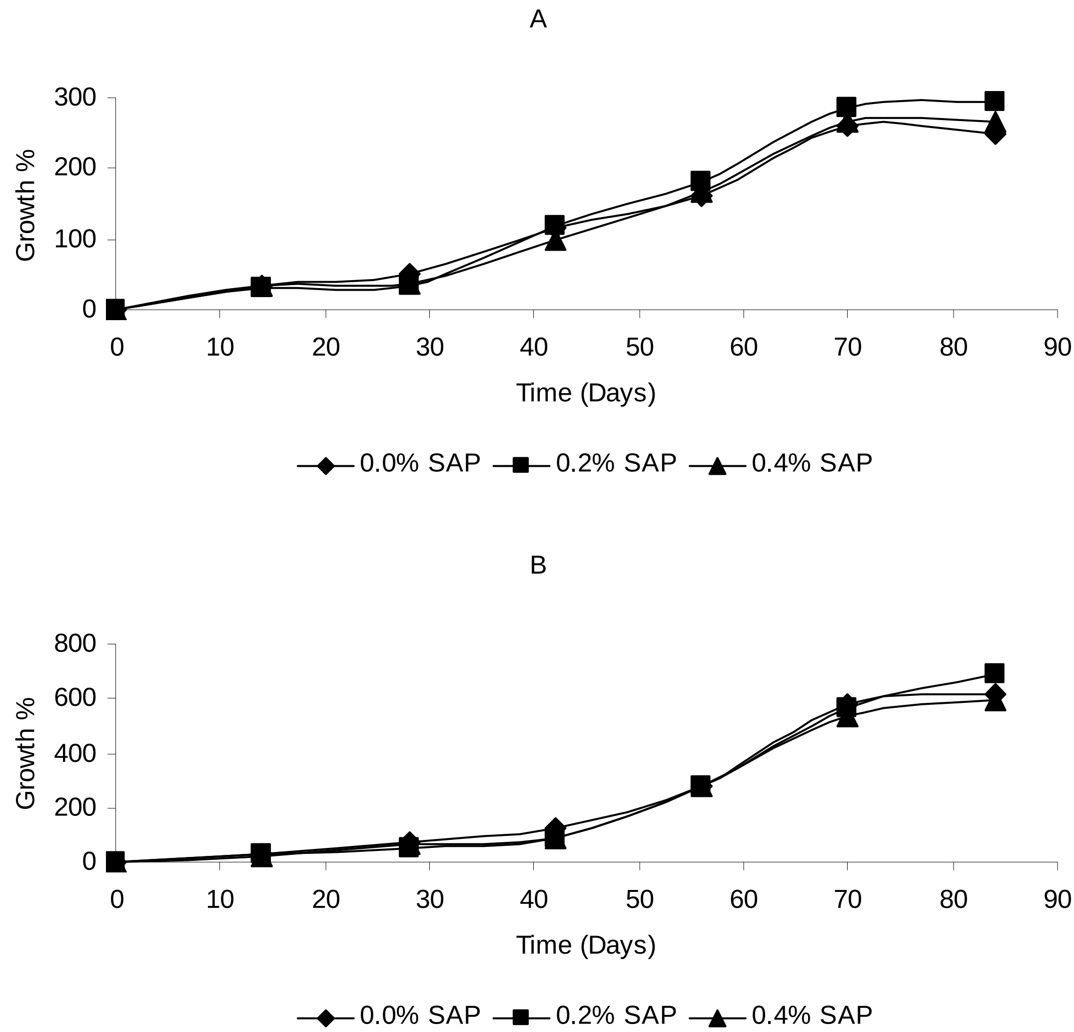


Figure 4.17: Growth rate of eggplants grown in test plot and irrigated with artificial wastewater with Cu and Zn metals within threshold value (AWM); **A:** Stem diameter, **B:** Plant height

Interesting results appeared in the pot experiment irrigated with AWSs (**Figure 4.18**). The polymer concentrations of 0.2 and 0.4% showed the higher growth rate in stem diameter and plant height compared with the control. The stem diameter at the end of vegetation period increased by 44 and 12% at 0.2 and 0.4% SAP, respectively, compared with 0% SAP. The plant height also increased by 51 and 13% at 0.2 and 0.4% SAP, respectively, compared with 0% SAP. Evidently, the SAP concentration of 0.2% was optimal for maximum growth of eggplants. The polymer was able to reduce the salt stress, which was favorable to enhance the eggplant growth.

The results coincided in general with the results of Hüttermann et al. (1997) and Hüttermann et al. (2009) in terms of that SAP reduce the salt stress for the plant. However, Hüttermann et al. (1999) reported an optimum amount of 0.4% polyacrylate hydrophilic polymer application to increase the root and plant growth for Aleppo Pine. Al-Harbi et al. (1999) reported the application of 0.3% sodium polyacrylamide hydrophilic polymer in a loamy sand soil to be sufficient for the maximum growth of cucumber.

The results of pot experiment irrigated with AWMs showed that at the end of the vegetation period the stem diameter and eggplant height were almost the same in all polymer concentrations (**Figure 4.19**). These results were different from those of Hüttermann et al. (2009), who reported that SAP bind heavy metals and mitigate their action on plants. They found that the presence of polyacrylate super absorbent polymer in irrigation water with concentration of 0.4% reduced the Pb concentration in roots of *Pinus sylvestris* by 96% compared with control. They also reported an increase by 320, 400 and 150%, respectively, of roots, branches, and leaves biomass of *Populus euphratica* grown on mine waste heaps amended with 0.6% SAP. Based on the results from the present study and the findings of other authors, it can be stated that the polymer efficiency on the plant responses varies due to the differences in the type of hydrophilic polymers and soils as well as on the plant species cultivated.

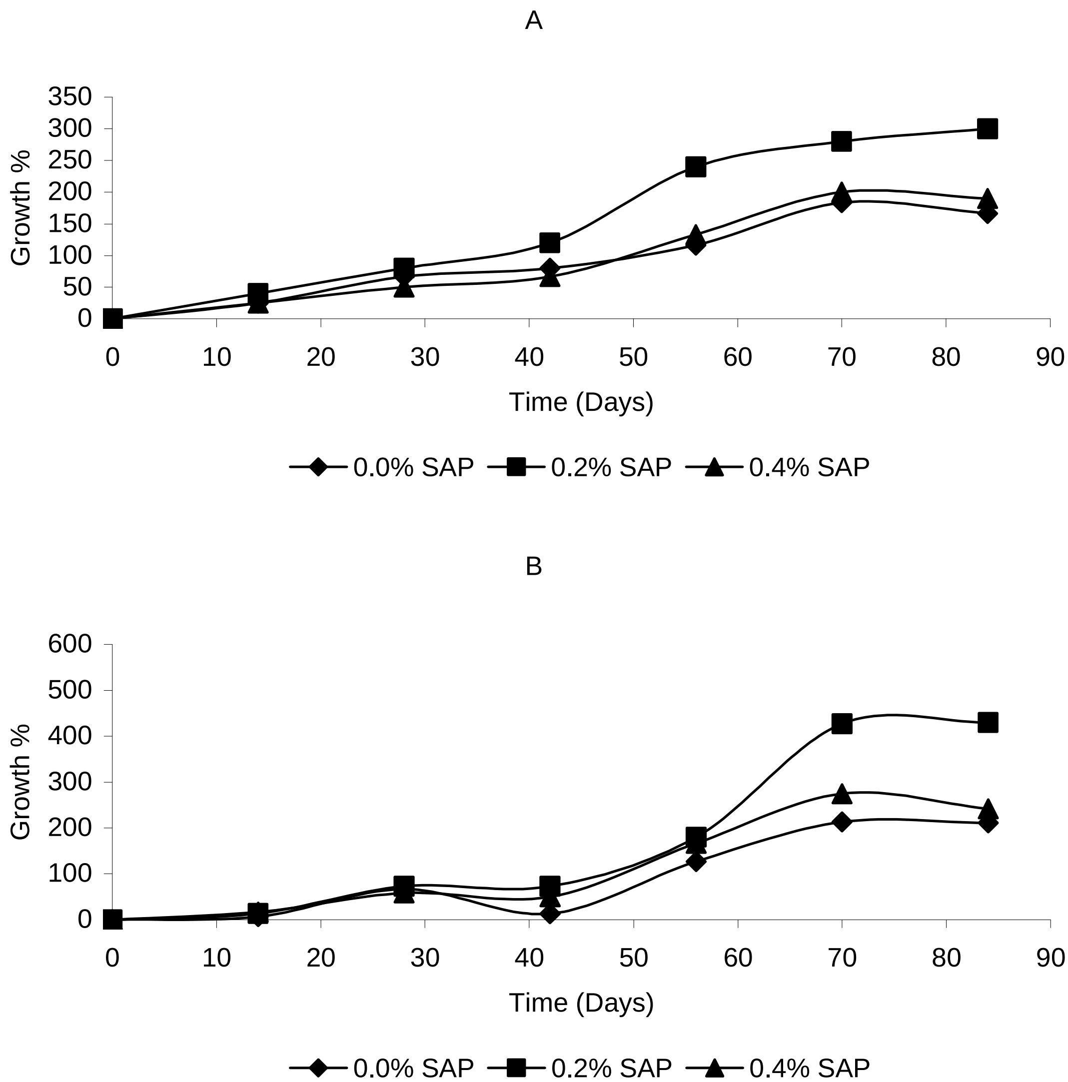
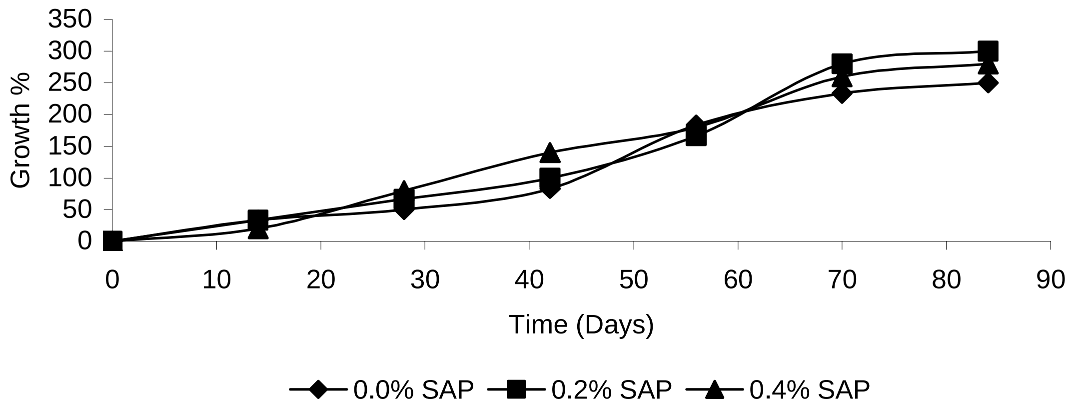


Figure 4.18: Growth rate of eggplants grown in pot experiment and irrigated with artificial wastewater with salt stress (AWSs); **A:** Stem diameter, **B:** Plant height

A



B

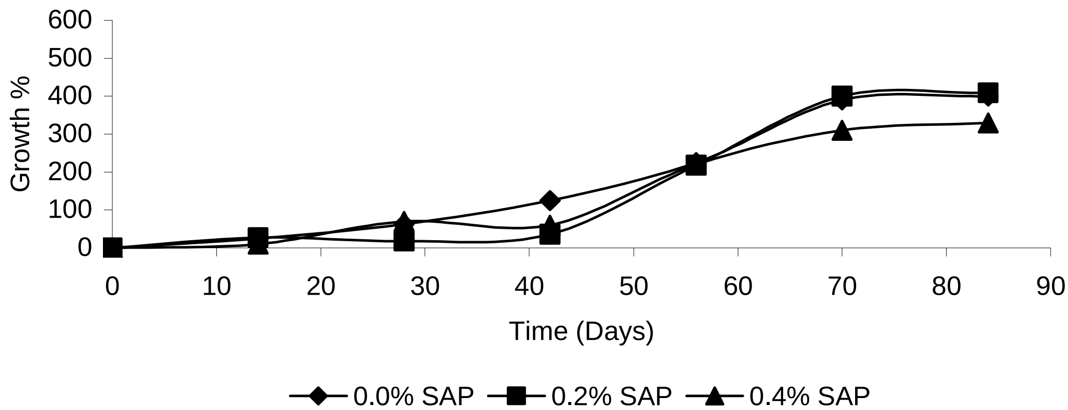


Figure 4.19: Growth rate of eggplants grown in pot experiments and irrigated with artificial wastewater with Cu and Zn metals stress (AWMs); **A:** Stem diameter, **B:** Plant height

In summary, under the present conditions a concentration of 0.2% SAP was the optimum for maximum eggplant growth. A comparison of the growth rates of stem diameter and plant height of eggplants grown in sandy soil amended with 0.2% SAP concentration and irrigated with different water qualities is displayed in **Figure (4.20)**. It followed that the growth rate of the stem diameter was almost the same in all irrigation water qualities. For the plant height, the results show that fresh water had an optimum effect on the growth rate of eggplant (0.2% SAP). The effect of the irrigation water qualities sequences as follow; FW > AWS and TW > AWM > AWSs and AWMs. This sequence was not surprising; it is due to the kind and amount of solutes in the irrigation water. Finally, it should be mentioned that a salt concentration within the threshold values (4000 µS/cm) accepted for irrigation purposes show the same response as the TW, which was used in the preparation of all artificial wastewaters.

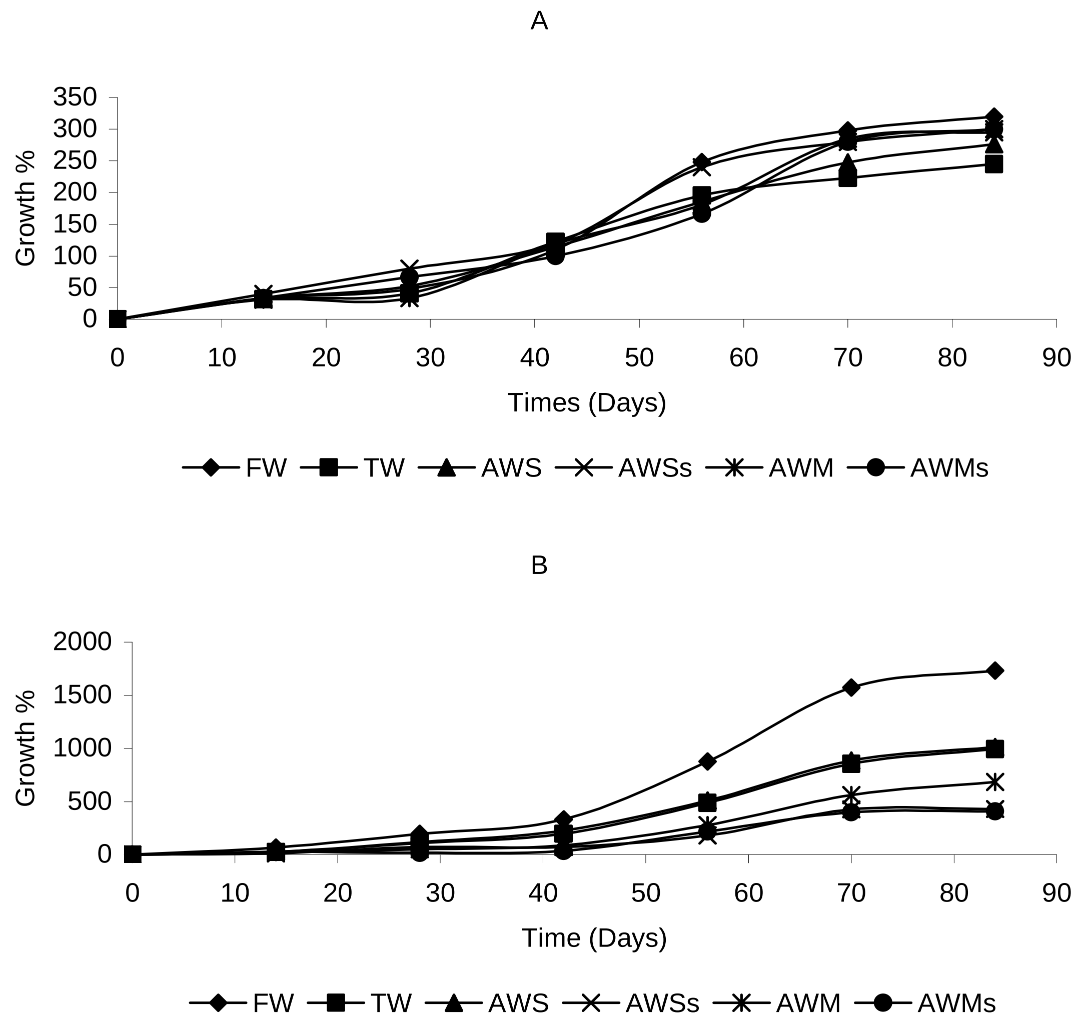


Figure 4.20: Effect of irrigation water qualities on the growth rate of eggplants grown in soil amended with 0.2% SAP; **A:** Stem diameter, **B:** Plant height

4.3.1.2 Biomass of eggplants

The highest biomass of eggplants in 2010 was determined at 0.2% SAP in test plot and pot experiments regardless of the irrigation water quality. Due to the sufficient high number of replicates, the total biomass data from test plot experiments were statistically analyzed by student's t-test with P values < 0.05. The comparison between the data showed that the total biomass in soils amended with 0.2 and 0.4% SAP was on the one hand significantly higher (0.2% SAP), on the other hand significantly lower (0.4% SAP) than in the control (**Table 4.14**). In general, the mean values of total biomass from the pot experiments showed quite similar trend in comparison with the test plot experiments (**Table 4.14)**. The irrigation water qualities in the test plot experiments were without any impact on the trend of the results.

However, the use of treated wastewater yielded in a higher production of biomass than of fresh water. The biomass results for all plant parts are shown in **Figure A2 and A3** (see **appendix**). The results corroborated the interpretion as mentioned in section 4.3.1.1. The SAP efficiency on plant responses was based on the differences in the type of hydrophilic polymers as well as on the type of soil and on the plant species cultivated. In addition, different plant species within the same genus showed a different response to the SAP concentrations. This was also reported by Islam et al. (2011) when using different amounts of a superabsorbent polymer (0, 30, 60, 90 and 120 kg/ha) in an erosion-prone arid sandy soil with limited irrigation. Applying an amount of superabsorbent polymer at 60 kg/ha, an increase of biomass by 87.3% and 18.3% of *Avena sativa L*., and *Avena nuda L*. was found, respectively.

Table 4.14: Plot and pot experiments in 2010: Total biomass of eggplants grown in sandy soil amended with different concentrations of SAP and irrigated with fresh water and treated wastewater (mean ± SD)

Polymer concentration and irrigation water quality	Biomass from test plot experiment [g/plant] n = 4	Biomass from pot experiment [g/plant] n = 2
Fresh water		
0.0%	181 ± 6.7 ^{a}	31 ± 5.7
0.2%	206 ± 3.3 ^{b}	47 ± 4.2
0.4%	159 ± 4.2 ^{c}	28 ± 4.2
Treated wastewater		
0.0%	182 ± 2.4 ^{a}	77 ± 4.2
0.2%	252 ± 5.7 ^{b}	91 ± 8.5
0.4%	170 ± 4.9 ^{c}	53 ± 4.2

The difference between letters within the same experiment means significant difference

The statistical data analysis of the experiments in 2011 showed a similar trend as from the year 2010. The total biomass in soils amended with 0.2% SAP was significantly higher than in soils with 0 and 0.4% SAP (**Table 4.15**). This was regardless of the irrigation water quality. The mean of total biomass from the pot experiments showed the same trend of the test plot experiments. In comparison between 0 and 0.4% SAP, the results showed that eggplant biomass in 0.4% SAP was significantly higher than in 0% SAP, with exception for the eggplants irrigated with fresh water and treated wastewater within the test plot experiment (**Table 4.15 and 4.16**). Further biomass results for all eggplant parts are shown in **Figure A4** (**see appendix**). These findings were interpreted as a consequence of polymer application. The polymer was more efficient with eggplants irrigated with salt and metal contaminated water, through mitigating the stress on the plant, and led to highest growth resulted in higher biomass compared with control. This was in agreement with Naderinasab et al. (2012), who found that the total biomass of sunflower was increased by 5% in sandy-loam soil amended with 510 g polyacrylate polymer in lysimeters (60 cm diameters and 100 cm heights), and irrigated with zinc polluted water, which was two times more than threshold value (4 mg/L) compared with control that grown in 0% polymers and irrigated with the same contaminated water.

From the findings of 2010 and 2011 in the present study, the most appropriate SAP concentration for eggplants in Jordanian sandy soil was the 0.2% (w/w).

Table 4.15: Plot experiments in 2011: Total biomass of eggplants grown in sandy soil amended with different concentrations of SAP and irrigated with different water qualities (mean ± SD, n = 4)

Polymer concentration and irrigation water quality	Biomass from test plot experiment [g/plant]
Fresh water	
0.0%	59 ± 4.8 [a]
0.2%	94 ± 6.0 [b]
0.4%	67 ± 6.2 [a]
Treated wastewater	
0.0%	73 ± 5.0 [a]
0.2%	84 ± 4.3 [b]
0.4%	77 ± 3.3 [a]
Artificial wastewater with salt	
0.0%	77 ± 3.3 [a]
0.2%	113 ± 4.0 [b]
0.4%	99 ± 2.4 [c]
Artificial wastewater with metal	
0.0%	67 ± 2.6 [a]
0.2%	100 ± 3.7 [b]
0.4%	94 ± 0.8 [c]

The difference between letters within the same experiment means significant difference

Table 4.16: Pot experiments in 2011: Total biomass of eggplants grown in sandy soil amended with different concentrations of SAP and irrigated with different water qualities (mean ± SD, n = 2)

Polymer concentration and irrigation water quality	Biomass from pot experiment [g/plant]
Artificial wastewater with salt stress	
0.0%	26 ± 3.5
0.2%	41 ± 0.7
0.4%	31 ± 1.4
Artificial wastewater with metal stress	
0.0%	7 ± 2.1
0.2%	29 ± 2.8
0.4%	15 ± 2.8

4.3.1.3 Fruit yields

In dependence of SAP amendment and irrigation water quality, the correlation (P values < 0.05) between data showed that the fruit yields of the eggplants in the test plot experiments produced by the soil amended with 0.2% SAP were significantly higher than of plants cultivated in the controls. The results were regardless of the irrigation water quality. The pot experiments showed the same trend for the average of total biomass. Also, the fruit yields produced by the soil amended with 0.2% SAP increased significantly, compared with control (**Table 4.17**). In soil amended with 0.4% SAP the yields were even lower than in plants from the control. The comparison between the two experiments showed that test plot experiments produced fruit yields higher than pot experiments irrigated with the same water quality and amended with the same polymer concentration. Reasons for these findings were already discussed in sections 4.3.1.1 and 4.3.1.2; the polymer efficacy on the plant growth was based on the type of hydrophilic polymers as well as on the type of soil and on the plant species cultivated.

Table 4.17: Test plot and pot experiments in 2010: Fruit yields of eggplants grown in sandy soil amended with different concentrations of SAP and irrigated with fresh water and treated wastewater (mean ± SD)

Polymer concentration and irrigation water quality	Fruit yields from test plot experiment [g/plant] n = 4	Fruit yields from pot experiment [g/plant] n = 2
Fresh water		
0.0%	413 ± 7.40 [a]	180 ± 7.10
0.2%	448 ± 10.1 [b]	225 ± 9.50
0.4%	304 ± 8.90 [c]	125 ± 11.3
Treated wastewater		
0.0%	727 ± 4.60 [a]	510 ± 7.10
0.2%	759 ± 6.90 [b]	550 ± 14.1
0.4%	497 ± 4.10 [c]	365 ± 9.90

The difference between letters within the same experiment means significant difference

The experiments on fruit yield from the year 2011 showed similar trends of the results as from the year 2010. In the test plot experiments the correlation ($P < 0.05$) between data showed eggplants fruit yields produced by the soil amended with 0.2% SAP were significantly higher than from control and from soil amended by 0.4% SAP. This was regardless of the irrigation water quality. Rehman et al. (2011) observed a significant increase of the kernel yield of rice in soil amended with 2.5 kg/ha carbonyl amide polymer by 2.39 t/ha compared with 2.25 t/ha produced on soil without amendments. In the present study, the WHC was improved and then the available water was increased by using 0.2% SAP (see section 4.2.2) and, therefore, the impact of water stress during the growing cycle was reduced. This can be attributed to a better crop establishment (Gharibzahedi et al., 2011) and an improvement of crop quality (Johnson and Piper, 1997). The comparison between the eggplant fruit yields produced in control and in 0.4% SAP shows that an application of 0.4% SAP was detrimental for eggplant fruit yields. With the exception of the irrigation with artificial wastewater with salt, the eggplants fruit yields from soil amended with 0.4% SAP were even lower than in control. Meanwhile, no significant difference between the control and 0.4% SAP from the test plot experiment irrigated with artificial wastewater with metal was observed (**Table 4.18**).

The mean of total biomass from the pot experiments showed the same trend compared with test plot experiments. The highest yields are found at 0.2% SAP (**Table 4.19**).

These findings of eggplant fruit yield in 2011 confirmed those of 2010. In general, it should be kept in mind that the polymer efficiency on the plant growth was based on the soil types as well as on plant species cultivated.

Table 4.18: Test plot experiment in 2011: Fruit yields of eggplants grown in sandy soil amended with different concentrations of SAP and irrigated with different water qualities (mean ± SD, n = 4)

Polymer concentration and irrigation water quality	Fruit yields from test plot experiment [g/plant]
Fresh water	
0.0%	138 ± 8.8 [a]
0.2%	173 ± 7.2 [b]
0.4%	23 ± 6.2 [c]
Treated wastewater	
0.0%	148 ± 6.7 [a]
0.2%	173 ± 8.1 [b]
0.4%	95 ± 5.2 [c]
Artificial wastewater with salt	
0.0%	63 ± 5.1 [a]
0.2%	260 ± 8.5 [b]
0.4%	125 ± 13.6 [c]
Artificial wastewater with metal	
0.0%	130 ± 6.8 [a]
0.2%	220 ± 7.8 [b]
0.4%	120 ± 2.5 [a]

The difference between letters within the same experiment means significant difference

Table 4.19: Pot experiments in 2011: Fruit yields of eggplants grown in sandy soil amended with different concentrations of SAP and irrigated with different water qualities (mean ± SD, n = 2)

Polymer concentration and irrigation water quality	Fruit yields from pot experiment [g/plant]
Artificial wastewater with metal stress	
0.0%	35 ± 8.5
0.2%	78 ± 5.7
0.4%	8 ± 4.2
Artificial wastewater with salt stress	
0.0%	0
0.2%	90 ± 12.7
0.4%	0

The profits were impossible to be calculated based on the Jordanian agricultural practice because each farmer follows different ways for irrigation, i.e., some times the farmer irrigates over the field capacity and some times lower. The irrigation intensity depends on the number of times and the amount of water supplied to the farm per week. The price of water depends on the amount of water used as well as on the source of water. In an interview with farmers they mentioned that the profits could be calculated at the end of each vegetation period after harvesting only because the profits are changeable from vegetation period to another. So, there are no systematics for agricultural practices in Jordan to be considered in the profit calculations of the present study.

Therefore, the profits in the present study were calculated for 0.2% SAP that showed the highest fruit yields and then compared with the control, which was irrigated with same water quality. With the exception of SAP amendment, eggplants were cultivated in sandy soil amended with 0.2% SAP and in control soil under same conditions as well as irrigated with same water quality and intensity. Therefore, only the cost of SAP (almost 2.5 €/kg) and the eggplant fruit yield produced were considered within the profits calculation. The other costs were excluded from the calculations because they were the same for 0.2% SAP and for the control.

The profits per hectare were -456, -618, 2185 and 446 Euro for the FW, TW, AWS and AWM, respectively (the results with minus means the farmer losing money instead of gaining profit from using SAP) (**Table 4. 20**). A clear result was that the highest profits gained from SAP application could be achieved in comparison with the control (0% SAP) and fresh water irrigation when eggplants are irrigated with AWS (2185 €/ha). This is due to the capability of SAP to mitigate the salt stress on eggplants. The profits, which could be achieved from the yields of eggplants that are irrigated with AWM cannot be realized at present because the metals already precipitated at the top few cm of soil. A clarification of this question requires soil with different (lower) pH.

Table 4.20: Eggplant fruit yield profits from soil amended with 0.2% SAP and irrigated with different water qualities in the test plot experiment

Irrigation water quality and SAP concentration		Eggplants yield [kg/ha] and price of fruit yield per hectare in Euro [1 kg = 1 €]	Total income per hectare after subtracting SAP price [1,016 €/ha]*	Profits gained by 0.2% SAP application compared with control [€/ha]
FW	0.0%	2,243	2,243	-456
	0.2%	2,803	1,787	
TW	0.0%	2,405	2,405	-618
	0.2%	2,803	1,787	
AWS	0.0%	1,024	1,024	2,185
	0.2%	4,225	3,209	
AWMs	0.0%	569	569	-325
	0.2%	1,260	244	
AWM	0.0%	2,113	2,113	446
	0.2%	3,575	2,559	
AWSs	0.0%	0	0	447
	0.2%	1,463	447	

* The 0.0% SAP profits were not considered within this subtraction due to SAP was not used.

4.3.2 Optimization of plant samples' preparation for element analysis

This test was carried out in order to optimize the plant samples' preparation for element analysis. The quality of the analyses was verified by comparing the concentrations of plant ash and of dry matter of the same samples. When the results of ash were recalculated to dry matter, the concentrations of Ca, K and Mg per kg were equal (**Figure 4.21**).

In the literature, element analyses for plant samples were carried out either by digesting the dry mater or the ash of the plants. Hochmuth et al. (2009) mentioned that element analysis in plant samples usually requires sample destruction either by dry ashing the sample or by dissolving the dry sample in one or more acids and then employing heat digestion. Schuhmacher et al. (1993) carried out analyses of chromium, copper, and zinc by digesting 1 g of dry matter of different vegetables (potato, onion, cabbage, tomato, etc.). Concentrations of Pb, Cd, Cu, and Zn were measured in tomato (*Licopersicon esculentum L.*), eggplant (*Solanum melongena L.*), and pepper (*Capsicum annum L.*) by digesting 0.25 g of powdered dry matter (Shilev and Babrikov, 2005). Kukier et al. (2004) investigated Ni and Co concentrations in *Alyssum murale* and *Alyssum corsicum* tissues by digesting the ash of the plant samples. Plank (1992) evaluated the published methods for developing new and improved procedures for elemental analysis in plant tissue samples and found that destruction of organic matter is necessary prior to a final digestion and should be done by dry ashing (high temperature combustion) or wet ashing (acid digestion). Both methods are based on the oxidation of organic matter using heat and/or acids.

Therefore, it was necessary to find out the most appropriate method for analyzing the eggplant samples. In the present study the dry ashing procedure recommended by Plank (1992) was used with all plant samples.

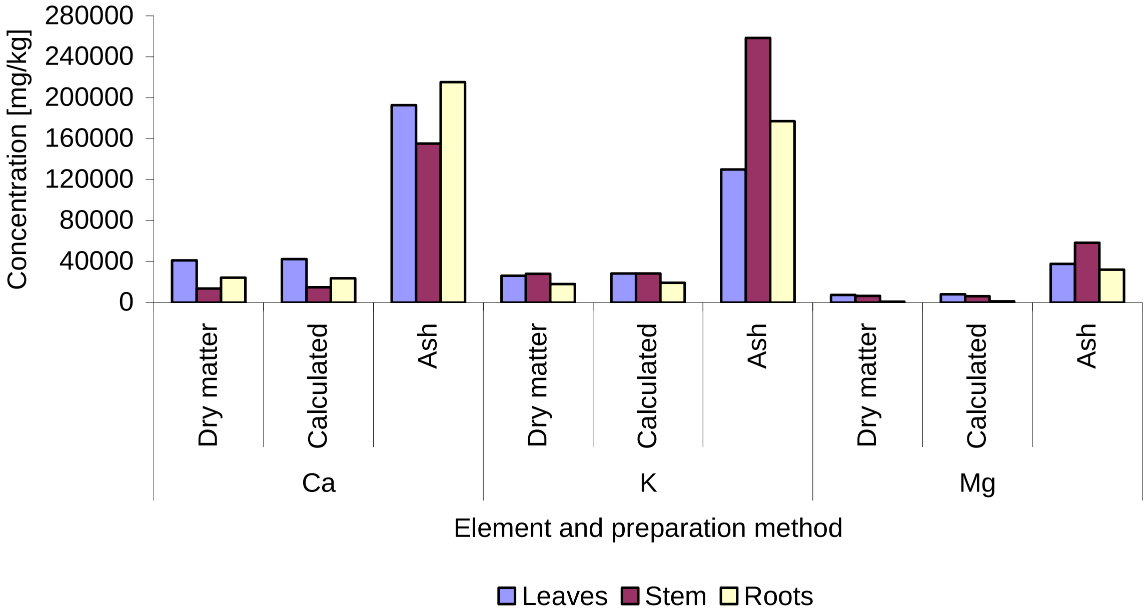


Figure 4.21: Comparison of analyses on Ca, K and Mg in eggplant leaves, stems and roots; dry matter: analysis of plant parts dried at 60 ^{o}C; calculated: recalculation of concentrations based on plant ash portions; ash: analysis of plant parts ashed at 550 ^{o}C.

4.3.3 Chemical element analysis

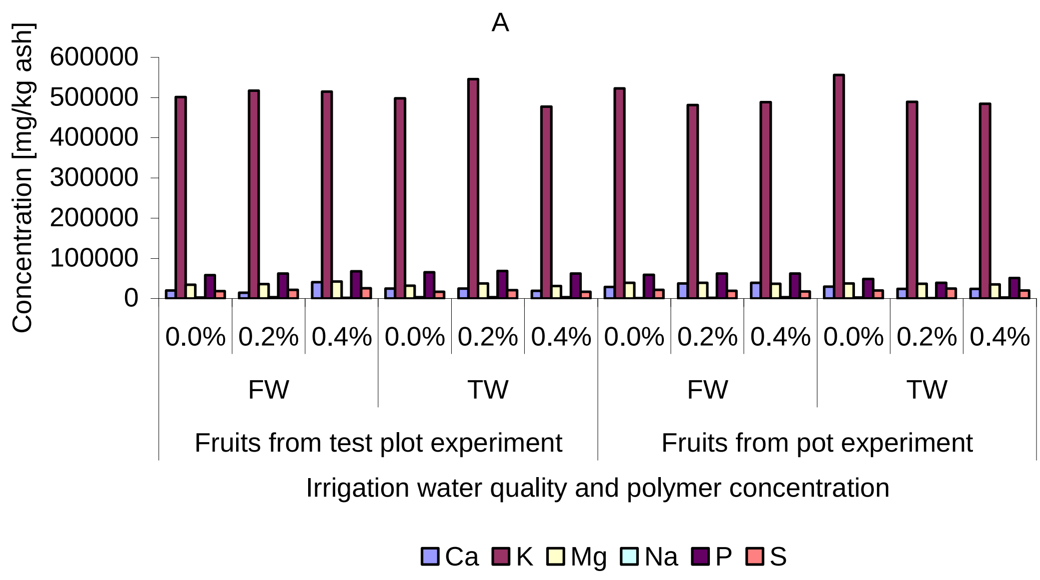
The homogeneity of results of the chemical element analyses in eggplant fruits was checked by analyzing 4 eggplant fruit samples collected from the same test plot. The element concentrations proved the homogeneity of the results. The concentrations of each element were almost equal in the 4 samples (**Figure A5**, see **appendix**)

The element analyses of the year 2010 showed no trend for the accumulation of Ca, Mg, K, Na, P and S in the eggplant parts regardless of the water irrigation quality and polymer concentration. A difference between test plot and pot experiments could not be found. **Figure 4.22** shows the element concentrations in eggplant fruits. Considering the heavy metals the fruit samples from the pot experiments show higher concentrations than those of the test plot experiments. However, a contiguous trend cannot be ascertained. Element concentrations in stems, leaves, and roots are shown in **figure A6, A7 and A8** (see **appendix**). These results were different from the findings of Qu and Varennes (2009), who found that *Lolium perenne L*. grown in a sandy loam soil with 0.07% of a polyacrylate polymer accumulate more Na than when it was grown in the same soil without polymer. Michalojc and Buczkowska (2008) mentioned that the highest potassium and magnesium concentrations were determined in eggplant fruits fertilized with ammonium sulfate. From this, follows that the fertilizer type has an effect on the metal accumulation by the plant.
The soil pH is considered as a key factor in metal uptake by crops. The increase of soil pH causes two opposite effects: On the one hand, it increases the uptake of free available metal ions, and on the other hand, the metal solubility and free metal activity in soil solution is decreased. The usual response in plant growth as mentioned by Kukier et al. (2004) is a decrease of metal concentrations in roots and shoots when the soil pH increases. This is due to limited metal solubility at high pH. Millaleo et al. (2010) mentioned that high pH causes Mn to be adsorbed onto soil particles, decreasing its availability. Similarly, Cieslinski et al. (1995) found that the Cd concentration in roots decreased by increasing soil pH. Plants grown in soil with low pH had significantly higher Cd concentration in the leaves than those planted in soil with pH above 6. This finding indicates that soil pH is a major parameter for the accumulation of metals by the plant tissue. Jordanian sandy soil under study has an alkaline pH, which varies from 8 to 9 (section 4.2.4). Therefore, the identity of results on the one hand and missing trends on the other hand in the present study are caused by the high pH as well as by the fact that fertilizers were not applied in this study.
Regarding the site specificity of element accumulation in the eggplants, different element concentrations were observed in different plant parts. The order of plant parts can be seen in **Table (4.21)**. The highest concentration of K, Cu, P and S were in the fruits, whereas Ca, Fe,

and Na were enriched in the roots. Mg and Zn were enriched in the stem, and Mn in the leaves. Shilev and Babrikov (2005) found an accumulation of Pb, Cd, Zn, and Cu in different parts, depending on the type of crop. The elements could be accumulated in roots (tomato), in fruit (pepper), and in leaves (eggplant). From this follows that each plant has a different pattern of element accumulation in the plant parts.

Table 4.21: Sequential arrangement of different parts of eggplants based on the content of elements concentration

Element	Plant Parts
Ca and Fe	Root > Leaf > Stem > Fruit
K and Cu	Fruit > Stem > Root > Leaf
Mg	Stem > Leaf > Fruit > Root
Na	Root > Stem > Fruit > Leaf
P, S	Fruit > Root > Leaf > Stem
Mn	Leaf > Root > Fruit > Stem
Zn	Stem > Root > Fruit > Leaf



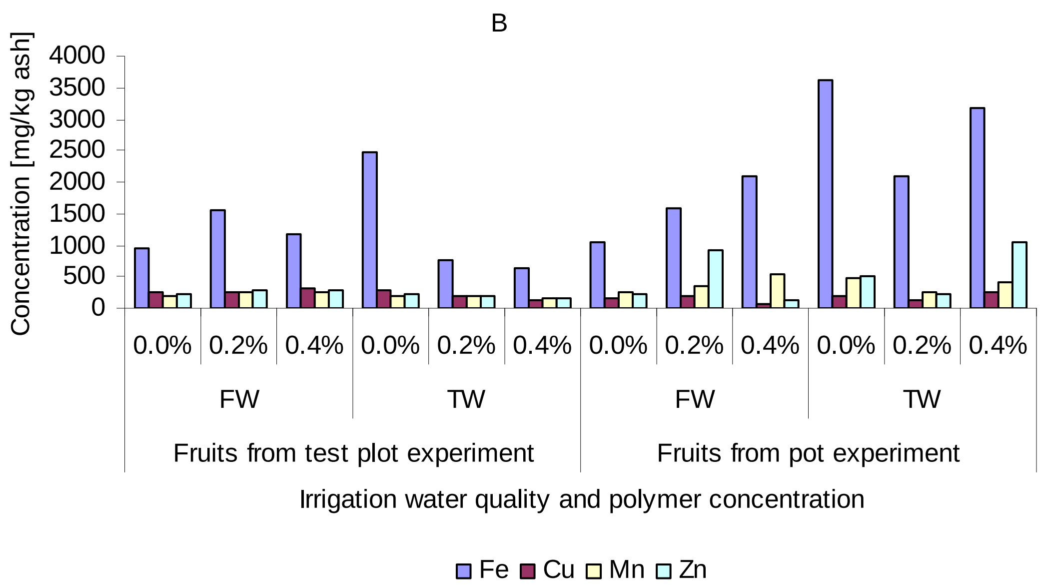


Figure 4.22: Effect of irrigation water quality and polymer concentration on element concentrations in eggplant fruits from the year 2010; **A:** Ca, K, Mg, Na, P and S. and **B:** Fe, Cu, Mn and Zn. Cd and Pb were below detection limits (0.05 and 0.2 mg/kg).

The element analysis in 2011 were analogous to those in the year 2010 as no trends for element accumulation in eggplant parts were observed regardless to the water irrigation quality and polymer concentrations. **Figure 4.23** shows the element concentrations in eggplant fruits. The enrichment of elements in the fruits in the pot experiments was confirmed. The element concentrations in stems, leaves and roots are summarized in **Figure A9, A10 and A11** (see **appendix**). In the pot experiments, none of the heavy metals spiked to the artificial wastewater showed any concentration differences within the eggplants. The polymer concentration did not have any effect on the element concentration. This indicates once more that the elements precipitated in soil due to the alkaline pH of Jordanian sandy soil.

Regarding the site specificity of element accumulation in the eggplant parts, the results confirmed the results from year 2010. The element concentrations determined in the different plant parts showed the same trend (**Table 4.20**).

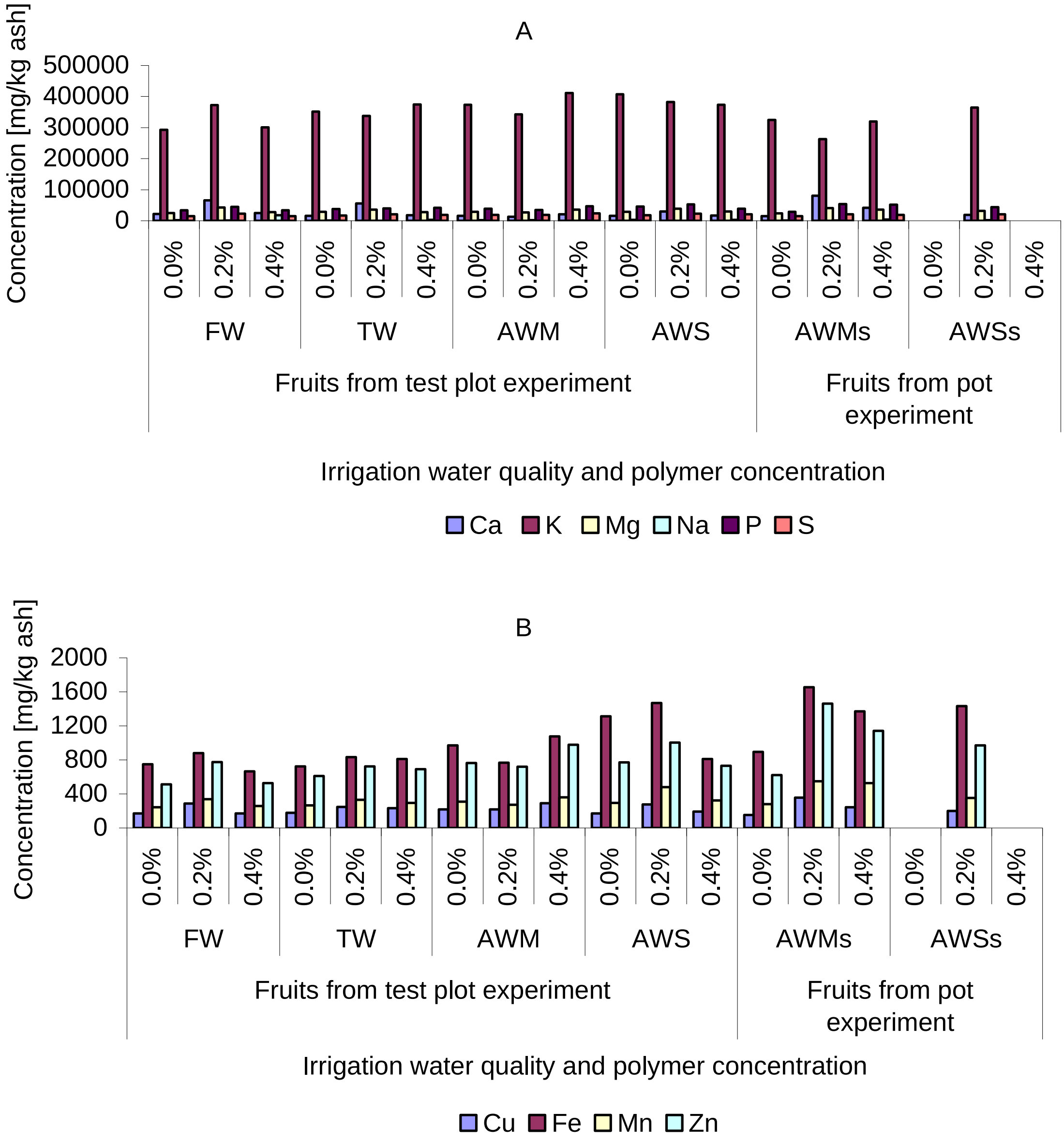


Figure 4.23: Effect of irrigation water quality and polymer concentration on the element concentrations in eggplant fruits from the year 2011; **A:** Ca, K, Mg, Na, P and S. and **B:** Cu, Fe, Mn and Zn. Cd and Pb were below detection limits (0.05 and 0.2 mg/kg).

4.4 Bacterial study

4.4.1 Total bacterial count

The total bacterial counts (TBCs) decreased with increasing polymer concentration. The highest TBCs were found at TW and AWS irrigation, whereas the TBCs under FW irrigation were very low compared with the other irrigation water qualities (**Figure 4.24**). This could be interpreted due to the original sandy soil that is poor in organic and nutritional supplements as well as the FW. These results are different from those of El-Hady and Abo-Sedera (2006). They found in sandy soil amended with polyacrylate hydrogel (2 g/plant pit) an increase of TBCs by 113%, 25%, 15% and 16% for bacteria, *Azotobacter* sp., fungi and actinomycetes, respectively. In an additional study, El-Hady et al. (2009) found when sandy soil was amended with acrylamide hydrogel of 0.1, 0.15 and 0.2% (w/w); the TBCs were 33, 35 and 36 x 10^6, respectively. On the other hand, increasing the metal concentration in soil caused the decrease in TBCs (Rajapaksha et al., 2004). Soil water stress deactivated the microbial biomass in general (Whiteley et al., 2003). However, Griffiths et al. (2003) showed that by soil moisture regime the physiological status of the bacterial community can be adjusted and as a result, bacterial communities in soil turn out to be water stress-resistant. Environmental factors such as temperature, pH, oxygen, and nutrients were found the most important limiting factors for bacterial growth in soil and thus the bacterial species varies in their biotic potential or capacity for population growth (Christian-Albrechts, 2009). The results of the present study showed that SAP has an irreversibly high affinity for the adsorption of elements (section 4.2.6). The original sandy soil was poor in organic and nutritional supplements (section 4.2.9), and the high adsorption potential of SAP restrained to a certain degree the elements from availability. Saadoun and AL-Momani (1996) mentioned that the nutrient availability as well as soil mechanical properties, i.e., soil texture and pore size, affects the bacterial growth and development. Therefore, the decrease of TBCs by increasing the SAP concentration could be understood as a result of irreversibly adsorbed essential elements by SAP thus making these elements less or rare accessible to the bacterial populations. The present study showed that the TBCs of rhizosphere are higher than that of plant hole soil. The results were in agreement with those of Gonzalez-Franco et al. (2009). It is well known that the rhizosphere soil contains many bacteria that feed on sloughed-off plant cells, termed rhizodeposition, and the proteins and sugars released by roots. Therefore, rhizosphere region is the highly preferable habitat for the proliferation, activity, and metabolism of numerous microorganisms.

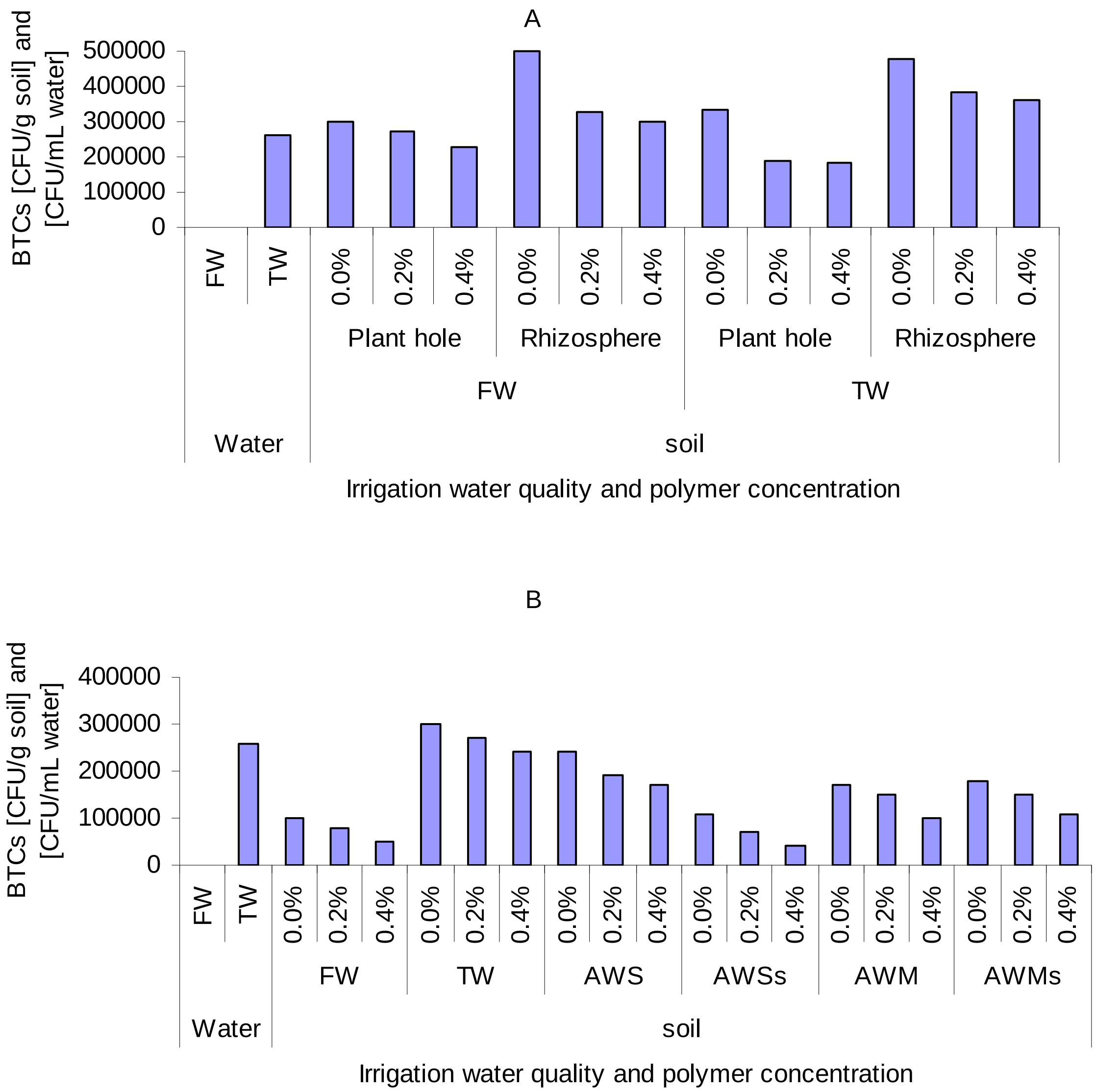


Figure 4.24: Total bacterial counts (TBCs) in Jordanian sandy soil amended with different concentrations of SAP and irrigated with different water qualities; **A:** From year 2010, **B:** From year 2011. **CFU:** Colony forming unit

4.4.2 Biochemical identification

15 bacterial isolates were recovered from the soil of the field. Bacterial isolation and identification were made according to their morphological and biochemical characteristics (**Table 4.22 and 4.23**). To assure the bacterial identification, 3 known bacterial genera were used as an identification control. These included a gram-positive (*Staphyllococcus aureus* ATCC 25923) and gram-negative bacteria, which consisted of *E. coli* ATCC 25922 and

Pseudomonas aeruginosa ATCC 27850. The results proved that the soil isolates consisted only of three bacterial genera. These genera were *Klebsiella pneumoniae*, *Corynebacterium diphtheriae* and *Bacillus subtilis*. The presence of *K. pneumoniae*, which is very common and ubiquitous occurring in humans (Podschun and Ullmann, 1998), and *C. diphtheriae*, which is a pathogenic bacterium (Weinrauch and Zychlinsky, 1999) in soil, was due to the irrigation with wastewater from the treatment plant of Mutah University. Therefore, the occurrence of these two genera along with the *B. subtilis* was not unexpected to be within the soil samples. Especially that the bacterial isolates from treated wastewater contain already these two bacterial species (**Table A1 and A2, see appendix**).

Table 4.22: Biochemical tests that carried out for the fifteen local bacterial isolates

Isolate number	Catalase	Oxidase	Motility	SIM	Citrate	Urease	Hydrogen sulfide	Gas formation
1	+	weak	-	-	-	-	-	-
2	+	+	-	-	-	-	-	-
3	+	+	-	-	-	-	-	-
4	+	+	-	-	-	-	-	-
5	+	+	-	-	-	Weak positive	-	-
6	+	+	-	-	-	-	-	-
7	+	+	-	-	-	-	-	-
8	+	+	-	-	-	-	-	-
9	+	+	-	-	-	-	-	-
10	+	+	-	-	-	-	-	-
11	+	+	-	-	-	-	-	-
12	+	+	-	-	-	Weak positive	-	-
13	+	+	-	-	-	+	-	-
14	+	+	-	-	-	-	-	-
15	+	+	-	-	-	Weak positive	-	-

+: Positive, -: Negative

Urease +: pink, -: yellow color. SIM (indole) / motility +: pink, -: no change.

Citrate +: blue color, -: green color

Catalase +: production of bubbles, -: no change. Oxidase +: purple color, - : no change

H_2S +: blackish stain color, -: no change

Table 4.23: Bacterial identification, cellular and colonial morphology

Sample Number	Gram stain	Cellular morphology	Colonial morphology	Name of bacteria
1	+	Non spore forming, V shape, Chine's letters	Light white small colonies	*Corynebacterium diphtheriae*
2	+	Non spore forming, V shape, Chine's letters	Light white small colonies	*Corynebacterium diphtheriae*
3	+	Spore forming, Bacilli shape	Large white colony	*Bacillus subtilis*
4	+	Spore forming, Bacilli shape	Large white colony	*Bacillus subtilis*
5	+	Non spore forming, V shape, Chine's letters	Light white small colonies	*Corynebacterium diphtheriae*
6	+	Non spore forming, V shape, Chine's letters	Light white small colonies	*Corynebacterium diphtheriae*
7	+	Non spore forming, V shape, Chine's letters	Light white small colonies	*Corynebacterium diphtheriae*
8	+	Non spore forming, V shape, Chine's letters	Light white small colonies	*Corynebacterium diphtheriae*
9	+	Spore forming, Bacilli shape	Large white colonies	*Bacillus subtilis*
10	+	Spore forming, Bacilli shape	Large white colonies	*Bacillus subtilis*
11	+	Spore forming, Bacilli shape	Large white colonies	*Bacillus subtilis*
12	-	Non spore forming, coccobacilli shape	Creamy mucoid colonies	*Klebsiella pneumoniae*
13	-	Non spore forming, coccobacilli shape	Creamy mucoid colonies	*Klebsiella pneumoniae*
14	+	Spore forming, Bacilli shape	Large white colonies	*Bacillus subtilis*
15	+	Non spore forming, V shape, Chine's letters	Light white small colonies	*Corynebacterium diphtheriae*

4.4.3 Metal resistant bacteria

The local bacterial isolates *B. subtilis*, *K. pneumoniae,* and *C. diphtheriae* were incubated for 24 h in different Cd concentrations containing nutrient broth media (100, 300, 700 and 1000 mg/L). After incubation the bacterial culture was streaked on the surface of Cd-free nutrient agar plates. The results demonstrated that *B. subtilis* and *K. pneumoniae* were able to survive at high concentration of Cd up to 1000 mg/L, whereas the *C. diphtheriae* was survived only at Cd concentration up to 100 mg/L (**Figure 4.25**). The high Cd concentration resistance of *K. pneumoniae* and *B. subtilis* in comparison to *C. diphtheriae* is probably due to different Cd adaptation mechanisms. These results were in agreement with the finding of Boularbah et al. (1992), who mentioned *B. subtilis* as Cd resistant species. Holmes et al. (1997) found out that *K. pneumoniae* overcomes cadmium toxicity by biotransformation of cadmium ions into photoactive nanometer-sized Cd particles deposited on the cell surface. These findings can be referred to different physiological states of the strains where some mechanisms of the Cd-resistant bacteria have been previously described. For example, Cd resistance may also be due to an energy-dependent efflux system such as in *Staphylococcus aureus* (Tynecka et al., 1981), or to a reduced transport of the metal into cells as described for *B. subtilis* (Laddaga et al., 1985). Based on the studies reported in literature, *B. subtilis* and *K. pneumoniae* were chosen to carry out the further Cd uptake experiments (section 4.4.4).

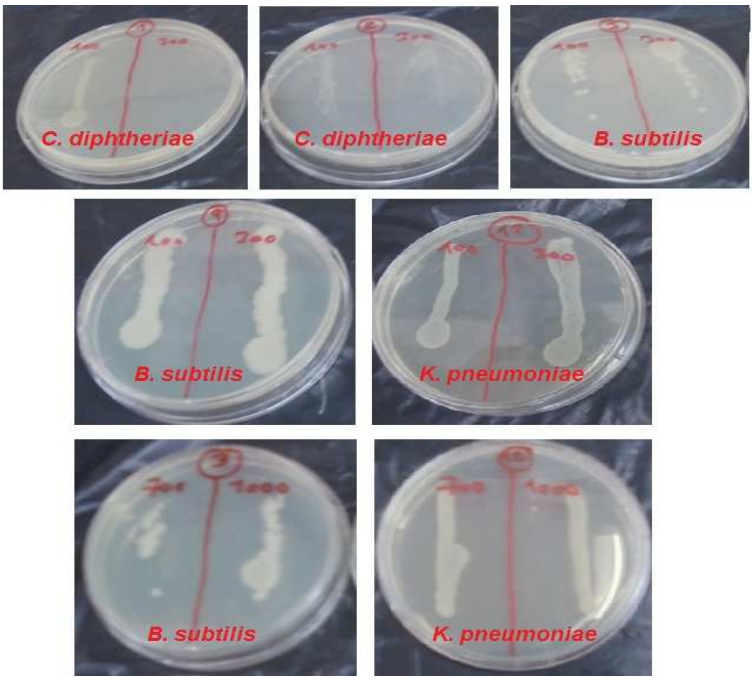


Figure 4.25: Ability of bacterial local isolates; *B. subtilis*, *K. pneumoniae* and *C. diphtheriae* to tolerate and survive in the presence of Cd

4.4.4 *In vitro* cadmium uptake by *B. subtilis* and *K. pneumoniae*

The cadmium uptake was investigated in two local bacterial isolates species, *B. subtilis* and *K. pneumoniae*. Both bacterial isolates showed a similar uptake profile of cadmium with different saturation levels. However, the cadmium uptake by the two bacterial strains differed with increasing amounts in the nutrient solution.

In *B. subtilis*, the highest cadmium uptake was found to be 12 µg/g biomass in the nutrient solution with cadmium concentration 300 mg/L (**Figure 4.26**). In *K. pneumoniae*, the maximum cadmium uptake was 83 µg/g biomass. It occurs in the nutrient solution with a cadmium concentration of 200 mg/L (**Figure 4.27**). *B. subtilis* showed a cadmium adsorption and uptake of 84% and 16% of the total cadmium biosorption, respectively. By *K. pneumoniae* the cadmium adsorption and uptake were 61% and 39% of the total cadmium biosorption, respectively. *K. pneumoniae* showed a higher relative cadmium accumulation than *B. subtilis* (47, 10 and 86% for the biosorption, adsorption and uptake, respectively).

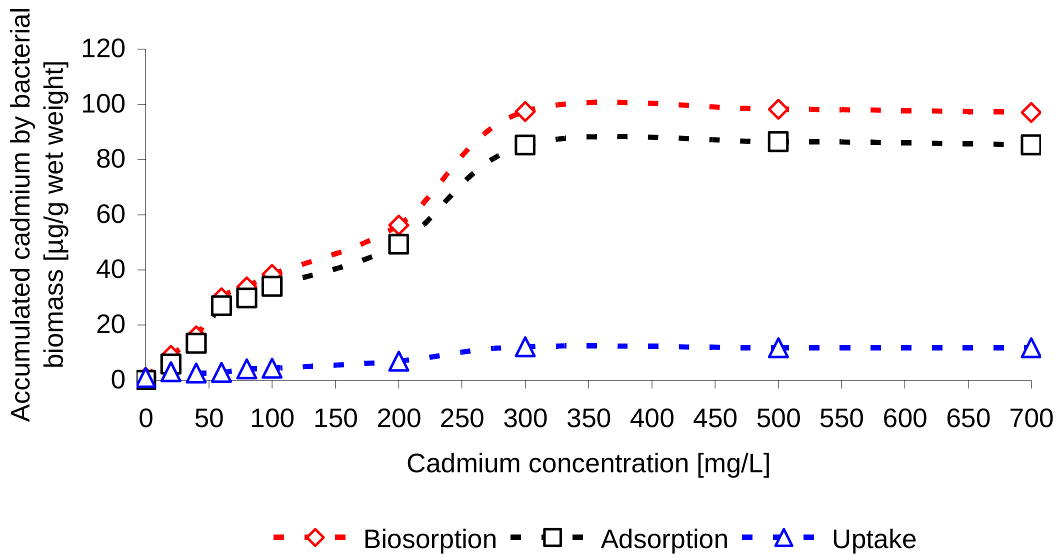


Figure 4.26: Cadmium biosorption, adsorption and uptake of *B. subtilis* at different cadmium concentrations

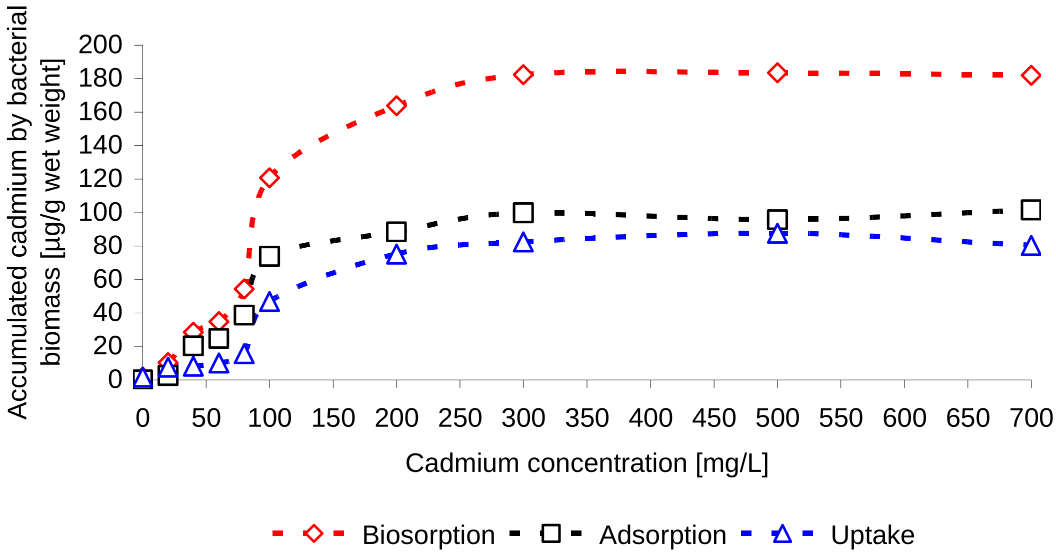


Figure 4.27: Cadmium biosorption, adsorption and uptake of *K. pneumoniae* at different cadmium concentrations.

In order to compare between the quantitative uptake and adsorption of cadmium, the percentage of cadmium uptake and adsorption was plotted versus the concentration of cadmium in the nutrient solution. **Figure 4.28** shows that in *B. subtilis* the minimum concentration of cadmium that gives 50% of maximum cadmium uptake is equal to 150 mg/L. In *K. pneumoniae*, the minimum concentration of cadmium that gives 50 % of maximum cadmium uptake is 100 mg/L (**Figure 4.29)**. Both strains, *B. subtilis* and *K. pneumoniae* are efficient cadmium scavenger from the surrounding host environment. A comparison of the minimum concentration of cadmium that produced 50 % uptake of cadmium gave a marked advantage for *K. pneumoniae* over *B. subtilis*.

In general, several bacterial species have developed different resistance mechanisms against heavy metals including cadmium (Nies and Silver, 1995). One of the resistance mechanisms can be ATP-independent, non-specific, fast, and governed by the chemiosmotic gradient across the cell membrane. Other resistance mechanisms are ATP dependent, slower, and more metal-specific (Khleifat et al., 2006). The natural and industrial processes release in increasing amounts heavy metals to microbial surroundings. Microbes have shown different mechanisms to tolerate the stress caused by heavy metals (Nies, 1995). These mechanisms of heavy metals resistance include extracellular precipitation, reduction to less toxic compounds, and membrane efflux that involves an active expelling transport of metals outside the cell (Khleifat et al., 2006). Genes responsible for metal resistance are chromosomal or plasmid dependent (Odermatt et al., 1994, Solioz and Odermatt, 1995). For example *qnr*-containing plasmids have become widespread among fluoroquinolone-resistant bacteria including *Klebsiella* (Li and Nikaido, 2009). The multidrug efflux mechanism decreased susceptibility to tetracycline in *K. pneumoniae* (Schneiders et al., 2003). Several multidrug pumps including Bmr, Blt, and Bmr3 have been described earlier in *B. substilis* (Ohki and Tateno, 2004).

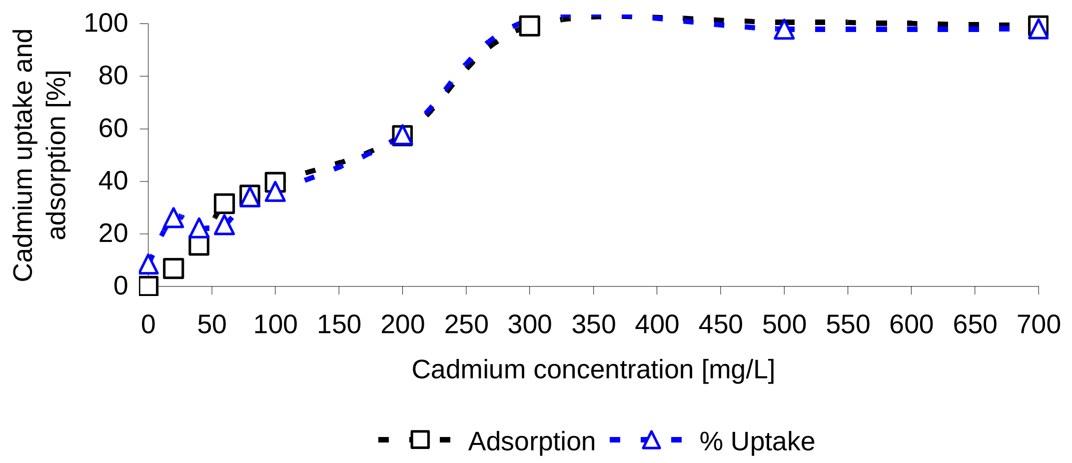


Figure 4.28: Percentage of cadmium adsorption and uptake by *B. subtilis* using different cadmium concentrations.

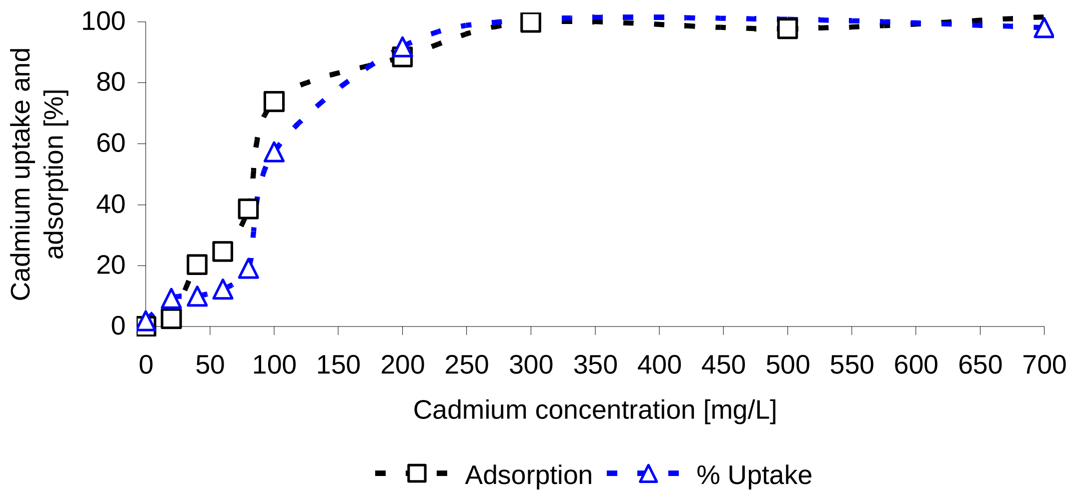


Figure 4.29: Percentage of cadmium adsorption and uptake by *K. pneumoniae* using different cadmium concentrations.

4.4.5 Polymer degradation test

The local bacterial isolates (**Table 4.23**) were unable to grow in SAP-containing media. Obviously, these bacteria were unable to use SAP as sole carbon and energy source. These results were in agreement with the findings of Stahl et al. (2000), who reported the inability of bacteria to degrade polyacrylate and polyacrylate/polyacrylamide polymers. Sutherland et al. (1997) pointed at that acrylic polymers are hardly biodegraded because of their crosslinkage and the stability of the polymeric backbone. In contrast, Hayashi et al. (1993) found that sodium acrylate oligomers were readily degradable by *Arthrobacter sp*. strain NO-18, isolated from soil samples. In this test, degradation rates accounted for 70-80% within 2 weeks. Additionally, Iwahashi et al. (2003) revealed that different kinds of bacteria are able to degrade different sodium acrylate polymers with different degradation percentages. The negative polymer degradation results from the present study were interpreted in accordance with Stahl et al. (2000). It is due to the carbon backbone stability of the polyacrylate polymers and high molecular mass. Therefore, the local bacterial isolates were unable to degrade the superabsorbent polymers.

Furthermore, Sutherland et al. (1997) reported that the white-rot fungus *Phanerochaete chrysosporium* was capable of degrading man-made crosslinked acrylic superabsorbent polymers. White-rot fungi and soil microbes cooperate synergistically in superabsorbent polymers degradation (Stahl et al., 2000). The present study was focused on the bacterial present in the soil. Further investigations should involve fungal isolates as individuals and in combination along with the bacterial isolates.

4.4.6 Endophytic bacterial study

Endophytic bacteria are defined as those bacteria that enter plant hosts without causing evidence of visible symptoms (Zinniel et al., 2002). Three main reasons substantiate the study of bacterial endophytes: They can promote plant growth, improve nitrogen nutrition, and some human pathogenic bacteria can colonize inside the plants (Tyler and Triplett, 2008). In this study, treated wastewater was used for irrigation purpose. Water of this provenience may contain various microorganisms such as bacteria, fungi, protozoa, and nematodes (Williams and Baun, 2003). From these microorganisms, endophytic bacteria were investigated in the eggplant parts, mainly in the fruits. The studies were focused on the aspect of bacteria that could be human pathogens. The screening results in all eggplant parts did not show the presence of endophytic bacteria. This is in contrast to the findings of Lin et al. (2009), who isolated the endophytic bacterial strain (Jaas ed1) of *B. subtilis* from the interior of an eggplant (*Solanum melogena L.*) stem. Various strategies were developed to manage a limitation of endophytic bacterial infestation (Ramesh and Phadke, 2012). These strategies comprise soil amendments, resistant varieties, use of bio-fumigants, soil solarization, the use of transgenic resistant plant, and plant growth promoting rhizobacteria. Nissinen et al. (2012) explained that endophytic bacterial communities were dependent on host plant species. The commercial importance of studying endophytic bacteria is reported by Ramesh and Phadke (2012). They mentioned that *Ralstonia solanacearum* is an important endophytic bacterial plant pathogen, which causes bacterial wilt for some economic important hosts including tomato, pepper, potato, tobacco, banana, eggplant, cowpea, peanut, cashew, papaya, and olive. In the present study no endophytic bacteria were detectable.

5. Conclusions

The application of crosslinked potassium polyacrylates as superabsorbent polymers in eggplants cultivation was evaluated at test plot and pot experiments. Eggplants were cultivated in sandy soil (pH > 7, EC > 279 µS/cm, TOC < 0.1% and N < 0.1 g/kg) amended with different concentrations of the SAP (0, 0.2 and 0.4%) and irrigated with different irrigation water qualities (FW, TW, AWM, AWMs, AWS and AWSs) under field conditions.
The highest eggplant growth rate, survival time, biomass and fruit yields in sandy soil were achieved at 0.2% SAP. Compared with the findings of Hüttermann et al. (1999), who found that the sufficient concentration of polyacrylate polymer for Aleppo Pine growth at 0.4% in sand soil. Al-Harbi et al. (1999), the best polyacrylamide concentration for cucumber growth was at 0.3 % in loamy sand soil. It can be concluded that the polymer efficiency on the plant growth varies in dependence of the soils and polymer types as well as on the plant species cultivated. Except of 0.2 % SAP, the available water for eggplants was not affected by the SAP concentrations, because the wilting point was increased parallel with water holding capacity.
As a reason of soil alkalinity, metals were precipitated at the superficial soil layer, therefore, no trend was observed for metal accumulation within the plant parts as well as for element concentrations in the soil samples regardless of the SAP concentration and irrigation water quality. The total organic carbon, total nitrogen and soil respiration were not affected by SAP application regardless of irrigation water quality. Due to the SAP amendment, the soil EC values proportionally increased to the SAP concentrations. Meanwhile, no correlation was observed between the soil pH and SAP concentrations.
SAP shows a high affinity to adsorb chemical elements like cadmium. Only 12-25% of the adsorbed cadmium could be desorbed from the sandy soil amended with 0.4% SAP, compared with 52-56 % from sandy soil without SAP amendment. This high capability of SAP to adsorb the elements irreversibly, which restrains to a certain degree the elements from availability, caused an adverse effect on the total bacterial count in soil with increasing of SAP concentration.
The treated wastewater from Mutah University is near the fresh water quality, and thus, could be used to replace FW for irrigation purpose. However, to check the ability of SAP to reduce metal and salt stress on the eggplants, artificial wastewaters with high metal and salt concentrations were additionally prepared. The artificial wastewaters with heavy metals and salt stress were introduced only in the pot experiments for avoiding field contamination. In comparison of test plot and pot experiments, the limited volume of the pots was particularly affecting the plant root growth, which reflects the low growth of the whole plant. Therefore, the test plot experiments were more appropriate to check the effect of SAP on the plant

growth, biomass, and fruit yields. In general, except of limited field area, the experimental field design was sufficient to investigate the effect of SAP amendments. Therefore, it is recommended to use larger fields in any future studies in order to enhance the ability to carry out more experiments with different irrigation intensities, different plant species and more replicates.

The calculated profits of eggplant yield from this study do mainly not cover the costs of SAP used. Therefore, economically the use of SAP as soil amendment in Jordanian sandy soil for eggplants cultivation can be considered as not successful. This might be different for perennial plants like date palms and other trees in order to survive the juvenile period for root development as reported by Agaba et al. (2010). The only economic benefit of SAP in sandy soils could be found in the application of salt water for irrigation at 0.2% SAP amendments. In general, this is in agreement with Hüttermann et al. (1997, 2009) in terms of that SAP reduces the salt stress for the plant. But, using such waters in combination with SAP, the impact on soils needs to be investigated on a long-term scale.

As reasons of soil amendment and host species-dependency of bacteria and plant, endophytic bacteria were not found in any eggplant parts. The SAP was not degradable by the local bacterial isolates containing *K. pneumoniae*, *C. diphtheriae,* and *B. subtilis*. The cadmium-resistant bacterial isolates (*B. subtilis and K. pneumoniae*) were active to accumulate cadmium (uptake and adsorption). These bacterial isolates are able to accumulate 30-50% cadmium compared with that adsorbed by the SAP. However, such natural organisms could be used in bioremediation to remove the metals from contaminated environments. This is worth to be investigated by microbiologists in any future studies, starting with re-identification of those bacteria using 16S ribosomal RNA, checking the responsible resistance gene, studying the ability of transforming these genes to nonpathogenic bacteria, etc.

6. Summary

The first applications of crosslinked superabsorbent polymers in agriculture worldwide go back to 1960's. However, these materials are not being used in agriculture so far in Jordan. Within the last few years, the applications of these polymers as soil amendments were frequently studied and became the focus of study by many scientists. Based on the possible advantages of the superabsorbent polymers in agriculture to enhance the WHC, plant available water, microbial activity of soil, plant growth, and crop yields increase. The sorption of inorganic pollutants may furthermore contribute to reduce heavy metal and salt stress to plants. Moreover, superabsorbent polymers are available at the market with a cheap price (one kilogram of SAP costs between 2 and 4 USD). The present study focused on the amendment of SAP on sandy soil under the main aspect of improving the irrigation efficiency and reuse of treated wastewater instead of fresh water for irrigation purpose for eggplants cultivation in Jordan. For this purpose, a test field was prepared at the Mutah University campus. The test plot and pot experiments were carried out under the field conditions during the vegetation periods of 2010 and 2011. Eggplants were cultivated in sandy soil amended by 0 (control), 0.2 and 0.4% of SAP (w/w) and irrigated with fresh water, treated wastewater, and artificial wastewaters. Heavy metals, major ions, and microorganisms were analyzed in irrigation water, soil, and plants. The latter were separated into leaves, stems, roots, and fruits, and focused on heavy metal accumulation. During the vegetation period, growth parameters and biomass production of test plants were determined. In addition, pot and laboratory tests were carried out to investigate the impacts of SAP on the water availability to plants and the sorption of cadmium in soil.

The quality of the treated wastewater used for irrigation was compared with Jordanian standards in order to assess its suitability for reuse. The TDS, BOD_5, COD, pH, DO, EC and the content of trace metals were determined. The quality of treated wastewater was close to the mean value of domestic drinking water in Jordan. Therefore, wastewater was spiked with metals and salts in order to check the ability of SAP to reduce metal and salt stress on the eggplants.

When sandy soil was amended with 0.2, 0.4 and 0.8% SAP the WHC increased by 21, 50 and 143% and the permanent wilting point was delayed by 6, 6 and 9 days, respectively. The increase of the polymer concentration in soil went parallel to the increase of WHC; however, available water did not increase. This effect became evident by the positive correlation of the wilting point with WHC. As an exception, at 0.2% SAP the highest available water appeared while the wilting point was the same in the control and soil amended with 0.2% SAP with a marked increase in the WHC in the 0.2% SAP. These obvious discrepancies between the stored water releases under the different conditions cannot be explained at present.

The electrical conductivity was decreased in all test plot and pot soil samples by 70-80% regardless of the irrigation water quality and polymer concentration compared with the original soil (without SAP amendment and irrigation). This decrease is explained by the duration of irrigation, which lasted 12 weeks and washed the soil from soluble salts. Meanwhile, the EC values were increased proportionally to the SAP concentrations compared with the control soil. The pH of all test plot and pot soil samples increased to 9.0 compared with the original soil, which was 8.0. Also, no correlation was observed between the pH and SAP concentrations. These findings have no explanation at present, because SAPs have different effects on the pH and EC of soils depending on synthetic materials and chemical structure of the SAP, and the physical and chemical characteristics of the soils. For that reason, further investigations of these characteristics are recommended for any future studies.

Sandy soil amended with 0.4% SAP is able to adsorb Cd 37 and 3 times higher than sandy soil without SAP amendment, depending on the use of Cd in soil solution or in deionized water, respectively. The adsorbed Cd was difficult to desorb from the sandy soil amended with 0.4% SAP, compared with the sandy soil without SAP amendment. The desorbed cadmium were 52-56% of that sorbed by sandy soil without SAP amendment, meanwhile, 15-25% of cadmium could be desorbed from that sorbed by sandy soil amended with 0.4% SAP. These findings are interpreted to be caused by a high irreversible sorption of Cd by the polymer.

The element concentrations in all soil samples as well as the metal accumulations in eggplant parts showed no trend related to the SAP concentrations and irrigation water qualities. These results indicated the precipitation of elements at the soil surface due to the high soil pH since elements are not available for the eggplants. The results of total nitrogen, TOC, and microbial activity of all soil samples did not show any relation to the SAP concentrations and irrigation water qualities. This effect was found to be caused by the poor nutrition in the sandy soil used.

Sandy soil amended with 0.2% SAP (w/w) showed the highest growth rate, biomass, and fruit yields for all irrigation water qualities used. It follows, that 0.2% SAP is the most appropriate concentration to be used as soil amendment in eggplants cultivation for the Jordanian sandy soil under study. As documented by the literature, the polymer efficacy on plant growth varies and is based on the soil types as well as on the cultivated plant species. In the present study, the growth rate, biomass, and fruit yield of eggplants from the test plot experiments were higher than in pot experiments. This indicated the plant growth impediment due to limited volume of the pots.

Total bacterial counts were decreased in soil by increasing the SAP concentration regardless of the irrigation water quality. This can be interpreted as a consequence of SAP that sorbs the essential elements irreversibly, thus making these elements less or rare accessible to the bacterial populations. Batch experiments are recommended to investigate the effect of SAP on bacterial growth in any future studies.

Two bacterial genera of the local isolates (*K. pneumoniae* and *B. subtilis)* were able to survive at high concentration of Cd (up to 1000 mg/L), therefore, they were chosen to carry out additional Cd uptake experiments. The cadmium uptake results gave evidence for the potential suitability of *B. subtilis* and *K. pneumoniae* as an efficient cadmium scavenger from the surrounding environment. *B. subtilis* has maximum cadmium uptake 12 µg/g biomass, which was detected at cadmium concentration of 300 mg/L, while in *K. pneumoniae* was 83 µg/g biomass was observed at cadmium concentration of 200 mg/L. These findings indicated the adaptation of different microbial mechanisms to tolerate heavy metal stress.

The local bacterial isolates were unable to degrade the SAP. As reported in the literature, bacteria in combination with fungi are able to degrade different polymers. Fungi were not considered in this study. Fungal isolates are suggested to be involved in further investigations, as individuals as well as in combination with bacterial isolates. While screening all parts of eggplants no any endophytic bacteria were found. This was likely due to the soil amendment and the host-species dependency of bacteria and plants.

Summing up, except of very small rise in water availability at 0.2% SAP, the irrigation efficacy was not improved by SAP application. The highest eggplant yield was achieved at 0.2% SAP. However, the income profit does not cover the costs of SAP used. Therefore, economically the use of SAP as soil amendment in Jordanian sandy soil for eggplant cultivation must be considered as not successful. This might be different for perennial plants like date palms in order to survive the juvenile period for root development. The only economic benefit of SAP in sandy soils could be found in the application of salt water for irrigation purpose. But, to use salty water for irrigation, the impacts on soils by the use of such waters in combination with SAP amended need more investigation. The treated wastewater from Mutah University is near the fresh water quality, and thus, could be used to replace fresh water for irrigation purpose. The test plot experiments were more appropriate to check the effect of SAP on the eggplants cultivation. In general, with the exception of limited field area, the experimental field design was sufficient to investigate the effect of SAP amendments. Finally, more investigations about the metal-resistant bacteria are recommended.

6. References

Abboud, M., Saeed, H.A., Tarawneh, K.A., Khleifat, K.M., Al Tarawneh, A. (2009): Copper uptake by *Pseudomonas aeruginosa* isolated from infected burn patients. Current Microbiology, 59(3), 282-287.

Abedi-Koupai, J., Asadkazemi, J. (2006): Effects of a hydrophilic polymer on the field performance of an ornamental plant (*Cupressus arizonica*) under reduced regimes. Iranian Polymer Journal, 15(9), 715-725.

Abu Jaber, F.J. (2012): New Routes for Synthesis of Environmentally Friendly Superabsorbent Polymers. Master thesis in Chemistry, Faculty of Graduate Studies, An-Najah National University, Nablus, Palestine.

Abu-Taleb, M., Salameh, E. (1994): Environmental management in Jordan: Problems and recommendations. Environmental Conservation, 21(1), 35-40.

Agaba, H., Orikiriza, L.J.B., Esegu, J.F.O., Obua, J., Kabasa, J.D., Hüttermann, A. (2010): Effects of hydrogel amendment to different soils on plant available water and survival of trees under drought conditions. Clean – Soil, Air, Water, 38(4), 328–335.

Akhter, J., Mahmood, K., Malik, K.A., Mardan, A., Ahmad, M., Iqbal, M.M. (2004): Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea. Plant, Soil and Environment, 50(10), 463–469.

Al Nasir, F., Batarseh, M. (2008): Agricultural reuse of reclaimed water and uptake of organic compounds: Pilot study at Mutah University wastewater treatment plant, Jordan. Chemosphere, 72, 1203-1214.

Al-Absi, K., Mohawesh, O. (2009): Olive oil mineral content of two local genotypes as influenced by recycled effluent irrigation under arid environment. Journal of the Science of Food and Agriculture, 89(12), 2082-2087.

Al-Bashabsheh, A.M. (2007): Wastewater and sludge quality in industrial estates, Jordan. Master Thesis of Science in Chemistry. Faculty of Graduate Studies, Mutah University, Jordan.

Al-Harbi, A.R., Al-Omran, A.M., Shalaby, A.A., Choudhary, M.I. (1999): Efficacy of a hydrophilic polymer declines with time in greenhouse experiments. HortScience, 34(2), 223–224.

Al-Humaid, A.I., Moftah, A.E. (2007): Effects of hydrophilic polymer on the survival of buttonwood seedlings grown under drought stress. Journal of Plant Nutrition, 30, 53-66.

Alqaisi, O., Ndambi, O.A., Hemme, T. (2009): Development of milk production and the dairy industry in Jordan. Livestock Research for Rural Development, 21(7), Article number 107.

Al-Zboon, K., Al-Ananzeh, N. (2008): Performance of wastewater treatment plants in Jordan and suitability for reuse. African Journal of Biotechnology, 7 (15), 2621-2629.

Ammary, B.Y. (2007): Wastewater reuse in Jordan: Present status and future plans. Desalination, 211, 164–176.

Andry, H., Yamamoto, T., Irie, T., Moritani, S., Inoue, M., Fujiyama, H. (2009): Water retention, hydraulic conductivity of hydrophilic polymers in sandy soil as affected by temperature and water quality. Journal of Hydrology, 373, 177-183.

Arp, W.J. (1991): Effects of source-sink relations on photosynthetic acclimation to elevated CO_2. Plant, Cell and Environment, 14, 869-875.

Assaf, K., Attia, B., Darwish, A., Wardam, B., Klawitter, S. (2004): Water as a human right: The understanding of water in the Arab countries of the Middle East - A four country analysis. Heinrich-Böll-Foundation, Hackesche Höfe, Rosenthaler, Berlin.

Atekwana, E.A., Atekwana, E.A., Rowe, R.S., Werkema Jr, D.D., Legall, F.D. (2004): The relationship of total dissolved solids measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbon. Journal of Applied Geophysics, 56, 281-294.

Ayers, R.S., Westcot, D.W. (2003): Water quality for agriculture. Food and Agriculture Organization of the United Nations (FAO), Rome 1970, Reprinted 1989, 1994.

Bai, W., Zhang, H., Liu, B., Wu, Y., Song, J. (2010): Effects of super-absorbent polymers on the physical and chemical properties of soil following different wetting and drying cycles. Soil Use and Management, 26, 253-260.

Bani-Domi, M. (2005): Trend analysis of temperatures and precipitation in Jordan. Umm Al-Qura University Journal of Educational, Social Sciences & Humanities, 17(1), 15-36.

Batarseh, M., Kreuzig, R., Bahadir, M. (2003): Residue analysis of organic pollutants in sediments from the Amman/Zarqa area in Jordan. Part I: Development of analytical method and distribution pattern of PAHs. Fresenius Environmental Bulletin 12(9), 972-978.

Batarseh, M.I. (2006): Fate of linear alkylbenzene sulfonates in wastewater treatment plants, Jordan. Fresenius Environmental Bulletin, 15(5), 431-436.

Batarseh, M.I. (2011): Sustainable use of wastewater and sludge in Jordan; residues of persistent organic pollutants, a review. Advanced water supply and wastewater treatment: A Road to Safer Society and Environment NATO Science for Peace and Security Series C: Environmental Security, 219-226.

Beesley, L., Moreno-Jiménez, E., Gomez-Eyles, J.L. (2010): Effects of biochar and greenwaste compost amendments on mobility, bioavailability and toxicity of inorganic and organic contaminants in a multi-element polluted soil. Environmental Pollution, 158, 2282-2287.

Berg, B. (2000): Litter decomposition and organic matter turnover in northern forest soils. Forest Ecology and Management, 133, 13-22.

Bhardwaj, A.K., Shainberg, I., Goldstein, D., Warrington, D.N., Levy, G.J. (2007): Water retention and hydraulic conductivity of cross-linked polyacrylamides in sandy soils. Soil Science Society of American Journal, 71(2), 406-412.

Blake, G.R., Hartge, K.H. (1986): Bulk density, in A. Klute, ed., Methods of Soil Analysis, Part I. Physical and Mineralogical Methods: Agronomy Monograph no. 9 (2nd ed.), 363-375.

Botti, C., Palzkill, D., Munoz, D., Prat, L. (1998): Morphological and anatomical characterization of six jojoba clones at saline and non-saline sites. Industrial Crops and Products, 9, 53–62.

Boularbah, A., Morel, J.L., Bitton, G., Guckert, A. (1992): Cadmium biosorption and toxicity to six cadmium-resistant gram-positive bacteria isolated from contaminated soil. Environmental Toxicology and Water Quality, 7, 237-246.

Bowman, D.C., Evans, R.Y. (1991): Calcium inhibition of polyacrylamide gel hydration is partially reversible by potassium. HortScience, 26(8), 1063-1065.

Buchholz, F.L., Graham, A.T. (1998): The structure and properties of superabsorbent polyacrylates. In modern superabsorbent polymer technology. Wiley-VCH, New York, 1998.

Carmi, A. (1993): Effects of root zone restriction on amino acid status and bean plant growth. Journal of Experimental Botany, 44(264), 1161-1166.

Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A., Joseph, S. (2007): Agronomic values of greenwaste biochar as a soil amendment. Soil Research, 45(8), 629-634.

Chapman, H.D., Pratt, P.F. (1961): Methods of analysis for soils, plants and water. University of California. Berkeley, CA, USA.

Chatzoudis, G.K., Rigas, F. (1998): Macroreticular hydrogel effects on dissolution rate of controlled-release fertilizers. Journal of Agricultural and Food Chemistry, 46, 2830-2833.

Chidumayo, E.N. (1994): Effects of wood carbonization on soil and initial development of seedlings in miombo woodland, Zambia. Forest Ecology and Management, 70, 353-357.

Cieslinski, G., Neilsen, G.H., Hogue, E.J. (1995): Effect of pH and Cd concentration on Cd accumulation by apple trees (*Malus domestica* Borkh) cv. Fuji. Proc. 2nd International Symposium on Diagnosis of Nutritional Status of Deciduous Fruit Orchards, Trento, Italy.

Collins, C.H., Lyne, P.M. (2004): Microbiological Methods, Eighth Edition. Hodder Arnold Publishers. ISBN-10: 0340808969.

Davies, L.C., Novais, J.M., Martins-Dias, S. (2004): Detoxification of olive mill wastewater using superabsorbent polymers. Environmental Technology, 25, 89-100.

Department of Statistics (DOS) (2006): Annual Report, Amman, Jordan.

Dorraji, S.S., Golchin, A., Ahmadi, A., (2010): The effects of hydrophilic polymer and soil salinity on corn growth in sandy and loamy soils. Clean – Soil, Air, Water, 38(7), 584-591.

Ekebafe, L.O., Ogbeifun, D.E., Okieimen, F.E. (2011): Polymer applications in agriculture. Biokemistri, 23(2), 81-89.

El-Hady, O.A., Abd El-Kader, A.A., Shafi, A.M. (2009): Physico-bio-chemical properties of sandy soil conditioned with acrylamide hydrogels after cucumber plantation. Australian Journal of Basic and Applied Sciences, 3(4), 3145-3151.

El-Hady, O.A., Abo-Sedera, S.A. (2006): Conditioning effect of composts and acrylamide hydrogels on a sandy calcareous soil. II-Physico-bio-chemical properties of the soil. International Journal of Agriculture and Biology, 8(6), 876-884.

Flanagan, L.B., Johnson, B.G. (2005): Interacting effects of temperature, soil moisture and plant biomass production on ecosystem respiration in a northern temperate grassland. Agricultural and Forest Meteorology, 130, 237-253.

Food and Agriculture Organization of the United Nations (FAO), (2007): The second country report on the state of the plant genetic resources for food and agriculture in Jordan.

Food and Agriculture Organization of the United Nations (FAO), (2008): Jordan Geography, climate and population.

Frantz, J.M., Locke, J.C., Pitchay, D.S., Krause, C.R. (2005): Actual performance versus theoretical advantages of polyacrylamide hydrogel throughout bedding plant production. HortScience, 40(7), 2040-2046.

Fritz, E., Knoche, D., Meyer, D. (1994): A new approach for rhizosphere research by X-ray microanalysis of microliter soil solutions. Plant and Soil, 161, 219-223.

Gee, G.W., Bauder, J.W. (1986): Methods of soil analysis, Part 1, Physical and mineralogical methods. Second Edition, Agronomy. Particle-size analysis, 383-411.

Gharibzahedi, S.M.T., Ghasemlou, M., Razavi, S.H., Jafarii, S.M., Faraji, K. (2011): Moisture-dependent physical properties and biochemical composition of red lentil seeds. International Agrophysics, 25, 343-347.

Gonzalez-Franco, A.C., Robles-Hernandez, L., Nuñez-Barrios, A., Strap, J.L., Crawford, D.L. (2009): Molecular and cultural analysis of seasonal actinomycetes in soils from *Artemisia tridentata* habitat. ΦYTON, ISSN 0031 9457, 78, 83-90

Granatstein, D., Kruger, C., Collins, H., Galinato, S., Garcia-Perez, M., Yoder, J. (2009): Use of biochar from the pyrolysis of waste organic material as a soil amendment. Final project report. Center for Sustaining Agriculture and Natural Resources, Washington State University, Wenatchee, WA, USA, 167 pp.

Greenberg, A.E., Clescerl, L.S., Eaton, A.D. (2005): Standard methods for the examination of water and wastewater 21th edition. American water works association/American public works association/water environment fedration. ISBN: 0875530478.

Griffiths, R.I., Whiteley, A.S., O'Donnell, A.G., Bailey, M.J. (2003): Physiological and community responses of established grassland bacterial populations to water stress. Applied and Environmental Microbiology, 69(12), 6961-6968.

Guidelines for brackish water irrigation in the Jordan Valley (2003): Jordan Valley Authority (JVA) Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ).

Guilherme, R.M., Reis, A.V., Paulino, A.T., Fajardo, A.R., Muniz, E.C., Tambourgi, E.B. (2007): Superabsorbent hydrogel based on modified polysaccharide for removal of Pb^{2+} and Cu^{2+} from water with excellent performance. Journal of Applied Polymer Science, 105, 2903-2909.

Guiwei, Q., de Varennes, A., Cunha-Queda, C. (2008): Remediation of a mine soil with insoluble polyacrylate polymers enhances soil quality and plant growth. Soil Use and Management, 24, 350-356.

Hadadin, N., Qaqish, M., Akawwi, E., Bdour, A. (2010): Water shortage in Jordan - Sustainable solutions. Desalination, 250, 197–202.

Hayashi, T., Mukouyama, M., Sakano, K., Tani, Y. (1993): Degradation of a sodium acrylate oligomer by an *Arthrobacter* sp. Applied and Environmental Microbiology, 59(5), 1555-1559.

Hedrick, R.M., Mowry, D.T. (1952): Effect of synthetic polyelectrolytes on aggregation, aeration, and water relationships of soil. Soil Science, 73, 427-442.

Hellenic Aid Programme of Greece (Ministry of Foreign Affairs) (2011): Development and implementation of an innovative, self-sufficient, brackish water treatment pilot plant for the production of drinking water for a Jordan Community. Project report at the Jordan University of Science and Technology in cooperation with the National Technical University of Athens.

Helmer, R., Hespanhol, I. (1997): Water pollution control - A guide to the use of water quality management principles. E and FN Spon, An imprint of Thomson Professional London, Weinheim, New York, Tokyo, Melbourne, Madras.

Hilber, I., Blum, F., Hale, S., Cornelissen, G., Schmidt, H.P., Bucheli, T.D. (2012): Total and bioavailable PAH concentrations in biochar - a future soil improver. EGU General Assembly, held 22-27 April, in Vienna, Austria, p. 5193.

Hochmuth, G., Maynard, D., Vavrina, C., Hanlon, E., Simonne, E. (2009): Plant tissue analysis and interpretation for vegetable crops in Florida. This document is HS964 one of a series in the Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Holmes, J.D., Richardson, D.J., Saed, S., Evans-Gowing, R., Russell, D.A., Sodeaul, J.R. (1997): Cadmium-specif ic formation of metal sulfide Q-particles by *Klebsiella pneumoniae.* Microbiology, 143, 2521-2530.

Horan, N.J. (1993): Biological wastewater treatment systems. Jones Wiley and Sons.

Huang, C., Webb, M.J., Graham, R.D. (1996): Pot size affects expression of Mn efficiency in barley. Plant and Soil, 178, 205-208.

Hüttermann, A., Orikiriza, L.J.B., Agaba, H. (2009): Application of superabsorbent polymers for improving the ecological chemistry of degraded or polluted lands. Clean – Soil, Air, Water, 37(7), 517-526.

Hüttermann, A., Zommorodi, M., Reise, K. (1999): Addition of SAPs to prolong the survival of *Pinus halepensis* seedlings subjected to drought. Soil and Tillage Research, 50, 295-304.

Hüttermann, A., Zommorodi, M., Wang, S. (1997): The use of hydrogels for afforestations of difficult stands: Water and salt stress. Affoerestation in semi-arid regions-findings and perspectives, proceedings. International Symposium in the Peoples Republic of China, 167-174.

Islam, M.R., Eneji, A.E., Ren, C., Li, J., Hu, Y. (2011): Impact of water-saving superabsorbent polymer on oat (*Avena* spp.) yield and quality in an arid sandy soil. Scientific Research and Essays, 6(4), 720-728.

ISO method 17155 (2003-06) Soil quality - Determination of abundance and activity of the soil microflora using respiration curves (ISO 17155:2002).

Iwahashi, M., Katsuragi, T., Tani, Y., Tsutsumi, K., Kakiuchi, K. (2003): Mechanism for degradation of poly(sodium acrylate) by bacterial consortium No. L7-98. Journal of Bioscience and Bioengineering, 95(5), 483-487.

Japan International Cooperation Agency (JICA), (2001): The study on water resources management in the Hashemite Kingdom of Jordan, Ministry of Water and Irrigation, Amman, Jordan.

Jayalakshmi, T., Krishnamoorthy, P., Kumar, R.G., Sivamani, P. (2011): The microbiological quality of fruit containing soft drinks from Chennai. Journal of Chemical and Pharmaceutical Research, 3(6), 626-630.

Jiries A., AL-Nasir, F., Beese, F. (2000): Pesticide and heavy metals residue in wastewater, soil and plants in wastewater disposal site near AL-Lajoun Valley, Karak-Jordan. Water, Air and Soil Pollution, 138, 97-107.

John, G.F. (2011): Towards improved application of super absorbent polymers in agriculture and hydrology: A cross-disciplinary approach. Master thesis of science. Graduate Faculty of Auburn University, Alabama.

Johnson, M.S. (1984): Effect of soluble salts on water absorption by gel-forming soil conditioners. Journal of the Science of Food and Agriculture, 35, 1063-1066.

Johnson, M.S., Piper, C.D. (1997): Cross-linked, water-storing polymers as aids to drought tolerance of tomatoes in growing media. Journal of Agronomy and Crop Science, 178, 23-27.

Jordan Institution for Standards and Metrology (JISM) (2008): Technical regulation report, document mandatory application: Water - Industrial reclaimed wastewater.

Jordanian meteorological department (JMD) (2004): Annual Report, Amman, Jordan

Kabiri, K., Zohuriaan-Mehr, M.J. (2004): Porous superabsorbent hydrogel composites: Synthesis, morphology and swelling rate. Macromolecular Materials and Engineering, 289, 653-661.

Kalavrouziotis, I.K., Apostolopoulos, C.A. (2007): An integrated environmental plan for the reuse of treated wastewater effluents from WWTP in urban areas. Building and Environment, 42, 1862-1868.

Kanazawa, S.H., Mori, K. (1995): Isolation of cadmium-resistant Bacteria and their resistance mechanisms. Soil Science and Plant Nutrition, 42, 731-736.

Khleifat, K., Abboud, M., Al-Shamayleh, W., Jiries, A., Al-Tarawneh, K. (2006): Effect of chlorination treatment on gram negative bacterial composition of recycled wastewater. Pakistan Journal of Biological Sciences, 9(9), 1660-1668.

Khleifat, K., Homady, M.H. (2000): Bacterial hemoglobin gene (vgb) transformed into *Escherichia coli* enhances lead-uptake and minimizes its adsorption. Pakistan Journal of Biological Sciences, 3(9), 1480-1483.

Khleifat, K.M., Nawayseh, K., Adjeroud, N.R., Khlaifat, A.M., Aljundi, I.H., Tarawneh, K.A. (2009): Cadmium-resistance plasmid affected Cd^{2+} uptake more than Cd^{2+} adsorption in *Klebsiella oxytoca*. Bioremediation Journal, 13(4), 159-170.

Kim, S.U., Cheong, Y.H., Seo, D.C., Hur, J.S., Heo, J.S., Cho, J.S. (2007): Characterisation of heavy metal tolerance and biosorption capacity of bacterium strain CPB4 (*Bacillus* spp.). Water Science and Technology, 55(1-2), 105-111.

Kim, S., Nadarajah, A. (2008): Development of double-layer hydrogels for agricultural applications. In AIChE Annual Meeting, Materials Engineering and Sciences Division.

Kisku, G.C., Barman, S.C., Bhargava, S.K. (2000): Contamination of soil and plants with potentially toxic elements irrigated with mixed industrial effluent and its impact on the environment. Water, Air, and Soil Pollution, 120, 121-137.

Kiziloglu, F.M., Turan, M., Sahin, U., Kuslu, Y., Dursun, A. (2008): Effects of untreated and treated wastewater irrigation on some chemical properties of cauliflower (*Brassica olerecea* L. var. botrytis) and red cabbage (*Brassica olerecea* L. var. rubra) grown on calcareous soil in Turkey. Agricultural Water Management, 95, 716-724.

Kukier, U., Carinne, A.P., Rufus, L.C., Scott, J.A., Richard, J.R. (2004): The effect of pH on metal accumulation in two *Alyssum* species. Journal of Environmental Quality, 33, 2090-2102.

Laddaga, R.A., Bessen, R., Silver, S. (1985): Cadmium-resistant mutant of *Bacillus subtilis* 168 with reduced cadmium transport. Journal of Bacteriology, 162(3), 1106-1110.

Lehmann, J., Joseph, S. (2012): Biochar for Environmental Management: Science and Technology. Earthscan, illustrated edition, ISBN 184407658X, 9781844076581.

Lehmann, J. (2007): Bio-energy in the black. *Frontiers in Ecology and the Environment,* 5(7), 381-387.

Lennartz, S., Braunmiller, K. (2012): Personal communication..

Lentz, R.D., Sojka, R.E. (2009): Long-term polyacrylamide formulation effects on soil erosion, water infiltration, and yields of furrow-irrigated crops. Agronomy Journal, 101, 305-314.

Li, X.Z., Nikaido, H. (2009): Efflux-mediated drug resistance in bacteria: An update. Drugs, 69(12), 1555-1623.

Lin, L., Qiao, Y.S., Ju, Z.Y., Ma, C.W., Liu, Y.H., Zhou, Y.J., Dong, H.S. (2009): Isolation and characterization of endophytic Bacillus subtilis Jaas ed1 antagonist of eggplant verticillium wilt. Bioscience, Biotechnology and Biochemistry, 73(1), 1489-1493.

Liu, M., Guo, T. (2001): Preparation and swelling properties of crosslinked sodium polyacrylate. Journal of Applied Polymer Science, 82, 1515-1520.

Liu, X., Tong, Z., Hu, O. (1995): Swelling equilibria of hydrogels with sulfonate groups in water and in aqueous salt solutions. Macromolecules, 28, 3813-3817.

Lubello, C., Gori, R., Nicese, F.P., Ferrini, F. (2004): Municipal-treated wastewater reuse for plant nurseries irrigation. Water Research, 38(12), 2939-2947.

Lyimo, N.E. (2010): Management practices in African eggplant cultivation: A case study of women farmers in Mvomero district, Morogoro region Tanzania. Master thesis, Van Hall Larenstein University of Applied Sciences, Wageningen, Netherlands.

McClellan, T., Deenik, J., Uehara, G., Antal, M. (2007): Effects of flashed carbonized macadamia nutshell charcoal on plant growth and soil chemical properties. International annual meetings, November 4-8, New Orleans, Louisiana.

McElligott, K.M. (2011): Biochar amendments to forest soils: Effects on soil properties and tree growth. Master of Science Thesis. College of Graduate Studies, University of Idaho.

MacFaddin, J.F. (1980): Biochemical tests for identification of medical bacteria. Lippincott Williams and Wilkins, 2nd edition. ASIN: B00924KT56

McLean, J.E., Bledsoe, B.E. (1992): Behavior of Metals in Soils. United States Environmental Protection Agency (EPA) EPA/540/S-92/018, Ground Water Issue.

Mediterranean environmental technical assistance program (METAP), (2001): Country report on water quality management and potential METAP interventions.

Michałojć, Z., Buczkowska, H. (2009): Influence of varied potassium fertilization on eggplant yield and fruit quality in plastic tunnel cultivation. Folia Horticulturae, 21(1), 17-26.

Mikkelsen, R.K. (1994): Using hydrophilic polymers to control nutrient release. Fertilizer Research, 38, 53-59.

Millaleo, R., Reyes-Diaz, M., Ivanov, A.G., Mora, M.L., Alberdi, M. (2010): Manganese as essential and toxic element for plants: transport, accumulation and resistance mechanisms. Journal of Plant Nutrition and Soil Science, 10(4), 470-481.

Ministry of Tourism and Antiquities (MOTA) and the World Bank, (2005): Third tourism development project, Secondary cities revitalization study, Karak, economic profile, Annex 3.

Mohammad, M.J., Ayadi, M. (2004): Forage yield and nutrient uptake as influenced by secondary treated wastewater. Journal of Plant Nutrition, 27(2), 351-365.

Mohsen, M.S. (2007): Water strategies and potential of desalination in Jordan. Desalination, 203, 27–46.

Murray, P.R., Rosenthal, K.S., Kobayashi, G., Michael A. Pfaller, M.A. (1998): Medical Microbiology. Mosby-Year Book, 3rd edition. ISBN-10: 0815190352.

Naderinasab, N., Hoodaji, M., Najafi, P. (2012): The effect of superabsorbant on phytoremediation of zinc polluted waters by sunflower. The 1st International and the 4th National Congress on Recycling of Organic Waste in Agriculture 26 – 27 April, in Isfahan, Iran.

Nazzal, Y., Mansour, M., Al Najjar, M., McCornick, P.G. (2000): Wastewater reuse law and standards in Jordan. The Ministry of Water and Irrigation, Amman, Jordan.

Nicholas, A., Peppas, J., Hilt, Z., Khademhosseini, A., Langer, R. (2006): Hydrogels in biology and medicine: from molecular principles to bionanotechnology. Advanced Materials, 18, 1345-1360.

Nies, D.H. (1995): The cobalt, zinc, and cadmium efflux system CzcABC from *Alcaligenes eutrophus* functions as a cation-proton antiporter in *Escherichia coli.* Journal of Bacteriology, 177(10), 2707-2712.

Nies, D.H., Silver, S. (1995): Ion efflux systems involved in bacterial metal resistances. Journal of Industrial Microbiology, 14(2), 186-99.

Nissinen, R.M., Männistö, M.K., van Elsas J.D. (2012): Endophytic bacterial communities in three arctic plants from low arctic fell tundra are cold-adapted and host-plant specific. FEMS Microbiology Ecology, 2012, 1-13.

Odermatt, A., Krapf, R., Solioz, M. (1994): Induction of the putative copper ATPases, CopA and CopB, of *Enterococcus hirae* by Ag^+ and Cu^{2+}, and Ag^+ extrusion by CopB. Biochemical and Biophysical Research Communications, 202, 44-48.

Ohki, R., Tateno, K. (2004): Increased stability of *bmr3* mRNA results in a multidrug-resistant phenotype in *Bacillus subtilis*. Journal of Bacteriology, 186(21), 7450-7455.

Okay, O., Sariisik, S.B. (1999): Swelling behavior for poly(acrylamide-c0-sodium acrylate) hydrogels in aqueous salt solutions: theory versus experiments. European Polymer Journal, 36(2), 393-399.

Okeola, F.O., Odebunmi, E.O. (2010): Comparison of Freundlich and Langmuir isotherms for adsorption of methylene blue by agrowaste derived activated carbon. Advances in Environmental Biology, 4(3), 329-335.

Orikiriza, L.J.B., Agaba, H., Tweheyo, M., Eilu, G., Kabasa, J.D., Hüttermann, A. (2009): Amending soils with hydrogels increases the biomass of nine tree species under non-water stress conditions. Clean – Soil, Air, Water, 37(8), 615-620.

Palágyi, S., Salzer, P., Mitro, A. (2006): Sorption, desorption and extraction of cadmium from some arable and forest soils. Journal of Radioanalytical and Nuclear Chemistry, 269(1), 103-113.

Peterson, D. (2009): Hydrophilic polymers – effects and uses in the landscape. Soviet Soil Science, 13(4), 111-115.

Pichtel, J., Bradway, D.J. (2008): Conventional crops and organic amendments for Pb, Cd and Zn treatment at a severely contaminated site. Bioresource Technology, 99, 1242-1251.

Plank, C.O. (1992): Plant analysis reference procedures for the southern region of the United State. Southern Cooperative Series Bulletin (SCSB # 368). ISBN: 1-58161-368-7

Podschun, R., Ullmann, U. (1998): *Klebsiella* spp. as nosocomial pathogens: Epidemiology, taxonomy, typing methods, and pathogenicity factors. Clinical Microbiology Reviews, 11(4), 589-603.

Popelářová, E., Voříšek, K., Strnadová, S. (2008): Relations between activities and counts of soil microorganisms. Plant, Soil and Environment, 54, 163-170.

Prasad, M.N.V., Freitas, H.M.O. (1999): Feasible biotechnological and bioremediation strategies for serpentine soils and mine spoils. Electronic Journal of Biotechnology 2(1), Issue of April 15.

Prell-Swaid, A., Schwedt, G. (1994): A screening procedure for heavy metals in soil extracts by alcohol dehydrogenase and urease inhibition. Acta Hydrochimica et Hydrobiologica, 22(2), 70-75.

Preston, C.M., Schmidt, M.W.I. (2006): Black (pyrogenic) carbon: A synthesis of current knowledge and uncertainties with special consideration of boreal regions. Biogeosciences, 3, 397-420.

Qu, G., De Varennes, A. (2009): Use of hydrophilic insoluble polymers in the restoration of metal-contaminated soils. Hindawi Publishing Corporation. Applied and Environmental Soil Science, 2009, Article ID 790687, 8 pages.

Raddad, K. (2005): Water supply and water use statistics in Jordan. IWG-Env, International Work Session on Water Statistics, Vienna, June 20-22.

Rajapaksha, R.M.C.P., Tobor-Kaplon, M.A., Baath, E. (2004): Metal toxicity affects fungal and bacterial activities in soil differently. Applied and Environmental Microbiology, 70(5), 2966-2973.

Ramesh, R., Phadke, G.S. (2012): Rhizosphere and endophytic bacteria for the suppression of eggplant wilt caused by *Ralstonia solanacearum*. Crop Protection, 37, 35-41.

Rao, C.R.M., Sahuquillo, A., Lopez Sanchez, J.F. (2008): A review of the different methods applied in environmental geochemistry for single and sequential extraction of trace elements in soils and related materials. Water Air Soil Pollut, 189, 291-333.

Ray, J.D., Sinclair, T.R. (1998): The effect of pot size on growth and transpiration of maize and soybean during water deficit stress. Journal of Experimental Botany, 49(325), 1381-1386.

Rayment, G.E., Higginson, F.R. (1992): Australian laboratory handbook of soil and water chemical methods. Inkata Press, Melbourne.

Rehman, A., Ahmad, R., Safdar, M. (2011): Effect of hydrogel on the performance of aerobic rice sown under different techniques. Plant, Soil and Environment, 57, (7), 321-325.

Saadoun, I., Al-Momani, F. (1996): Bacterial and streptomyces flora of some Jordan valley soils. Actinomycetes, 4(1), 95-99.

Sarafaz, Sh., Khani, M.R., Yaghmaeian, K. (2007): Quality and quantity survey of hospital wastewater in Hormozgan province. Iranian Journal of Environmental Health Science and Engineering, 4(1), 43-50.

Sari, A.I. (2009): Factors limiting bacterial growth in soil. Ecosystem modeling. Master Environmental Management, Department of Ecosystem Research, Christian-Albrechts University of Kiel, Germany.

Schneiders, T., Amyes, S.G.B., Levy, S.B. (2003): Role of AcrR and RamA in fluoroquinolone resistance in clinical *Klebsiella pneumoniae* isolates from Singapore. Antimicrobial Agents and Chemotherapy, 47(9), 2831-2837.

Schuhmacher, M., Domingo, J.L., Llobet, J.M., Corbella, J. (1993): Chromium, copper, and zinc concentrations in edible vegetables grown in tarragona province, Spain. Bulletin of Environmental Contamination and Toxicology, 50, 514-521.

Shahid, S.A., Qidwai, A.A., Anwar, F., Ullah, I., Rashid, U. (2012): Improvement in the water retention characteristics of sandy loam soil using a newly synthesized poly(acrylamide-co-acrylic Acid)/$AlZnFe_2O_4$ superabsorbent hydrogel nanocomposite material. Molecules, 17, 9397-9412.

Shackley, S., Sohi, S., Haszeldine, S., Manning, D., Masek, O. (2009): Biochar reducing and removing CO_2 while improving soils: A significant and sustainable response to climate change? Evidence submitted to the Royal Sosciety Geo-engineering Climate Enquiry. UK Biochar Research Center (UKBRC), working paper 2.

Shatanawi, M., Shammout, M., Naber, S. (2008): Water conflict among sectors and environmental use in Jordan. Water Culture and Water Conflict in the Mediterranean Area. Options Méditerranéennes, Series A, No. 83, Bari, Italy.

Shilev, S., Babrikov, T. (2005): Heavy metal accumulation in *Solanacae*-plants grown at contaminated area. Proceedings of the Balkan Scientific Conference of Biology in Plovdiv (Bulgaria) from 19th-21st of May (EDS. Grauev, B., Nikolova, M., Donev, A. p, 452-460).

Sivapalan, S. (2001): Effect of polymer on soil water holding capacity and plant water use efficiency. In Proceedings 10th Australian Agronomy Conference, Hobart, Tasmania, Australia.

Sjöberga, G., Nilssona, S.I., Perssonb, T., Karlsson, P. (2004): Degradation of hemicellulose, cellulose and lignin in decomposing spruce needle litter in relation to N. Soil Biology and Biochemistry, 36, 1761-1768.

Solioz, M., Odermatt, A. (1995): Copper and silver transport by CopB-ATPase in membrane vesicles of *Enterococcus hirae*. Journal of Biological Chemistry, 270, 9217-9221.

Specht, A., Harvey-Jones, J. (2000): Improving water delivery to the roots of recently transplanted seedling trees: The use of hydrogels to reduce leaf loss and hasten root establishment. Forest Research, 1, 117-123.

Stacey, S.P. (2007): New micronutrient fertilisers for alkaline soils. PhD thesis submitted to Soil and Land Systems School of Earth and Environmental Sciences. University of Adelaide Australia.

Stahl, J.D., Cameron, M.D., Haselbach, J., Aust, S.D. (2000): Biodegradation of superabsorbent polymers in soil. Environmental Science and Pollution research, 7(2), 83-88.

Steinbeiss, S., Gleixner, G., Antonietti, M. (2009): Effect of biochar amendment on soil carbon balance and soil microbial activity. Soil Biology and Biochemistry, 41(6), 1301-1310.

Stenström, J., Stenberg, B., Johansson, M. (1998): Kinetics of substrate-induced respiration (SIR): Theory. AMBIO: A Journal of the Human Environment. 27(1), 35-39.

Sutherland, G.R.J., Haselbach, J., Aust, S.D. (1997): Biodegradation of crosslinked acrylic polymers by a white-rot fungus. Environmental Science and Pollution research, 4(1), 16-20.

Syvertsen, J.P., Dunlop, J. (2004): Hydrophilic gel amendments to a sandy soil can increase growth and nitrogen uptake efficiency of citrus seedlings. HortScience, 39(2), 267-271.

Ta'any, R.A., Al Zu'bi, Y. (2007): Rainfall network optimization in Jordan as an example of Mediterranean Sea region. Journal of Food, Agriculture & Environment, 5(2), 284-288.

Temminghoff, E.J.M., Houba, J.G.V. (2004): Plant analysis procedures, 2nd edition. Kluwer Academic Publishers, Dordrecht, Netherlands.

Tongwa, P., Nygaard, R., Bai, B. (2012): Evaluation of a nanocomposite hydrogel for water shut-off in enhanced oil recovery applications: Design, synthesis, and characterization. Journal of Applied Polymer Science. DOI: 10.1002/APP.38258.

Torri, S.I., Correa, R.S. (2012): Downward movement of potentially toxic elements in biosolids amended soils. Hindawi Publishing Corporation. Applied and Environmental Soil Science, 2012, article ID 145724.

Tyler, H.L., Triplett, E.W. (2008): Plants as a habitat for beneficial and/or human pathogenic bacteria. Annual Review of Phytopathology, 46, 53-73.

Tynecka, Z., Gos, Z., Zajac, J. (1981): Energy-dependent efflux of cadmium coded by a plasmid resistance determinant in *Staphylococcus aureus*. Journal of Bacteriology, 147(2), 313-319.

Uleimat, A.A. (2011): Wastewater management in Jordan. 6th IWA Specialist Conference on Efficient Use and Management of Water. 29 March - 2 April, Dead Sea, Jordan

United States Environmental Protection Agency (EPA), (2008): Polycyclic Aromatic Hydrocarbons (PAHs). Office of Solid Waste, Washington, DC 20460.

Wang, L., Zhang, J., Wang, A. (2008): Removal of methylene blue from aqueous solution using chitosan-*g*-poly (acrylic acid)/montmorillonite superadsorbent nanocomposite. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 322, 47–53

Wardam, B. (2004): More politics then water: Water rights in Jordan. Global Issue Papers, No.11 (2) Berlin: The Heinrich Böll Foundation.

Watanabe, A., Takada, H., Sarno, Afandi, Adachi, T., Oki, Y., Senge, M. (2007): Assessment of degradation and generation of humus in a coffee soil affected by weed cover by means of a stable carbon isotopic ratio. European Journal of Soil Science, 58, 1042-1049.

Water Authority of Jordan (WAJ), (2006): Water quality and quantity. Comparison of surface water budget for 2004/2005 season with the long-term average, 1937-2005. Department of Statistics, Amman, Jordan.

Weinrauch, Y., Zychlinsky, A. (1999): The introduction of opoptosis by bacterial pathogens. Annual Review of Microbiology, 53, 155-187.

Whiteley, A.S., Griffiths, R.I., Bailey, M.J. (2003): Analysis of the microbial functional diversity within water-stressed soil communities by flow cytometric analysis and CTC+ cell sorting. Journal of Micobiological Methods, 54(2), 257-67.

William, J.F., Gary, J.K. (1990): Water absorption of hydrophylic polymers (hydrogels) reduced by media amendments. Journal of Environmental Horticulture, 8(3), 113-114.

Williams, M.M., Baun-Howland, E.B. (2003): Growth of *Escherichia coli* in model distribution system biofilms exposed to hypochlorous acid or monochloramine. Applied Environmental Microbiology, 69(9), 5463-5471.

Wolter, M., Wiesche, C., Zadrazil, F., Hey, S., Haselbach, J., Schung, E. (2002): Biologische Abbaubarkeit synthetischer superabsorbierender Bodenhilfsstoffe. Landbauforschung Völkenrode, 1(52), 43-52.

Zeineldin, F.I., Aldakheel, Y.Y. (2006): Hydrogel polymer effects on available water capacity and percolation of sandy soils at Al-Hassa, CSBE/SCGAB Annual Conference, Edmonton, Canada.

Zheng, Y., Hua, S., Wang, A. (2010): Adsorption behavior of Cu^{2+} from aqueous solutions onto starch-g-poly (acrylic acid)/sodium humate hydrogels. Desalination, 263, 170-175.

Zinniel, D.K., Lambrech, P., Harris, N.B., Feng, Z., Kuczmarski, D., Higley, P., Ishimaru, C.A., Arunakumari, A., Barletta, R.G., Vidaver, A.K. (2002): Isolation and characterization of endophytic colonizing bacteria from agronomic crops and prairie plants. Applied and Environmental Microbiology, 68(5), 2198-2208.

Zohuriaan-Mehr, M.J., Kabiri, K. (2008): Superabsorbent polymer materials: A Review. Iranian Polymer Journal, 17(6), 451-477.

Zohuriaan-Mehr, M.J., Omidian, H., Doroudiani, S., Kabiri, K. (2010): Advances in non-hygienic applications of superabsorbent hydrogel materials. Journal of Materials Science, 45(21), 5711-5735.

References available on internet

Countries of the world (2006): Geography, maps, flag, history, current ruler, area, population, capital, largest cities, languages, ethnicity/race, religion, literacy rate, economy and government. Accessed on 13.09.2012. Available at: http://www.studentsoftheworld.info/pageinfo_pays.php3?Pays=GER&Opt=climate

Davis, J.G., Wilson, C.R. (2005): Choosing a soil amendment, fact sheet number 7.235. Colorado State University. Accessed on 13.09.2012. Available at: http://www.ext.colostate.edu/pubs/garden/07235.pdf.

Dugan, E., Verhoef, A., Robinson, S., Sohi, S. (2010): Bio-char from sawdust, maize stover and charcoal: Impact on water holding capacities (WHC) of three soils from Ghana. 19th World Congress of Soil Science, Soil Solutions for a Changing World, 1-6 August, Brisbane, Australia. Published on DVD. Accessed on 13.09.2012. Available at: http://www.iuss.org/19th%20WCSS/Symposium/pdf/1158.pdf.

Hoshi, T. (2001): Growth promotion of tea trees by putting bamboo charcoal in soil. International Conference on O-Cha Culture and Science, Session II, p. 147-150, Tokai University, Shizuoka, Japan. Accessed on 13.09.2012. Available at: http://www.hoshi-lab.info/cha/paper.pdf.

Jhurry, H. (2006): Agricultural polymers. Food and Agricultural Research Council, Réduit, Mauritius. Accessed on 13.09.2012 Available at: http://www.uom.ac.mu/Polymer/files/downloads/articles/uom18.pdf.

Jordan Memory Tours, (2012): Climate & Geography. Accessed on 13.09.2012 Available at: http://www.jordanmemorytours.com/s74-67-Climate_&_Geography-About%20Jordan.html.

Josiah Hunt, J., DuPonte, M., Sato, D., Kawabata, A. (2010): The basics of biochar: A natural soil amendment. Soil and Crop Management, SCM-30. Accessed on 13.09.2012. Available at: http://www.ctahr.hawaii.edu/oc/freepubs/pdf/SCM-30.pdf.

Guidelines for Municipal Wastewater Irrigation (2000): Municipal Program Development Branch. Edmonton, Alberta T5K 2J6. Accessed on 13.09.2012. Available at: http://environment.gov.ab.ca/info/library/7268.pdf.

Maryland cooperative extension, (2009): Soil amendments and fertilizers. Home and Garden Mimeo number 42. Accessed on 13.09.2012. Available at: http://www.hgic.umd.edu/content/documents/hg42_002.pdf.

Ministry of Water and Irrigation (MWI), (2012a): Water policy. Available at Ministry homepage.

Ministry of Water and Irrigation (MWI), (2012b): Irrigation water policy. Available at Ministry homepage.

Ministry of Water and Irrigation (MWI), (2012c): Wastewater policy. Available at Ministry homepage.

Scott, C., Faruqui, N.I., Raschid, L. (2004): Wastewater use in irrigated agriculture, confronting the livelihood and environmental realities. International Development research Centre (IDRC), International Water Management Institute (IWMI) and CABI Publishing. UK. Accessed on 13.09.2012. Available at: http://www.idrc.ca/en/ev-31595-201-1-DO_TOPIC.html#begining.

USDA Natural Resources Conservation Service, (2008): Soil Quality Indicators. Accessed on 13.09.2012. Available at: http://soils.usda.gov/sqi/assessment/files/bulk_density_sq_physical_indicator_sheet.pdf.

USDA Natural Resources Conservation Service, (2011): Soil Quality Indicators. Accessed on 13.09.2012. Available at: http://soils.usda.gov/sqi/assessment/files/EC_sq_chemical_indicator_sheet.pdf.

Wardam, B., (2007): Pricing of Domestic Water in Jordan. Aaccessed on 13.09.2012 Available at: http://www.watsonblogs.org/meef/2007/07/pricing_of_domestice_water_in.html.

Zheng, W., Sharma, B.K., Rajagopalan, N. (2010): Using biochar as a soil amendment for sustainable agriculture. Sustainable Agriculture Grant Program, Illinois Department of Agriculture. Unpublished data. Accessed on 13.09.2012 Available at: https://www.ideals.illinois.edu/bitstream/handle/2142/25503/Using%20Biochar%20as%20a%20Soil%20Amendment%20for%20Sustainable%20Agriculture-final%20report%20from%20Zheng.pdf?sequence=2.

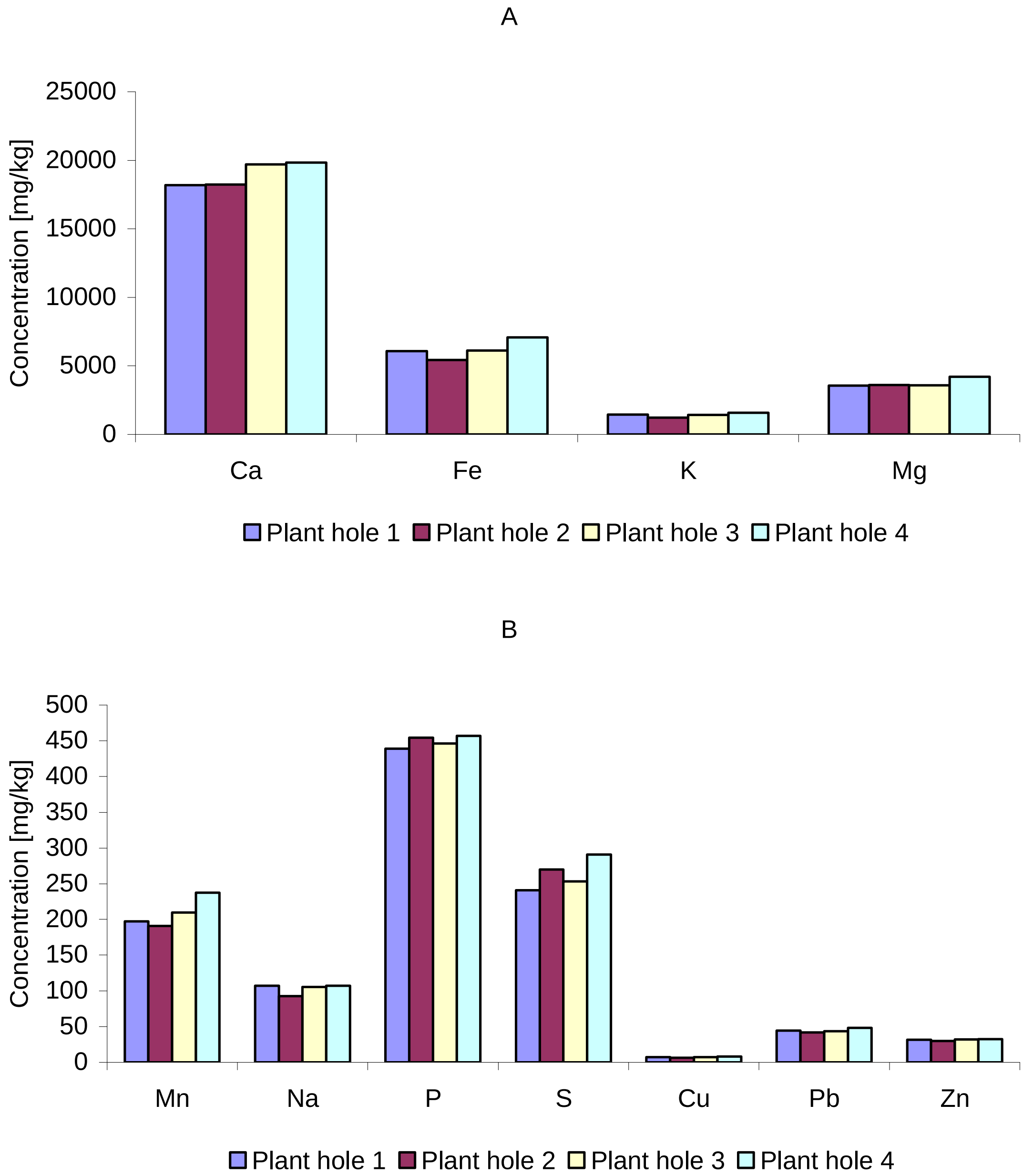
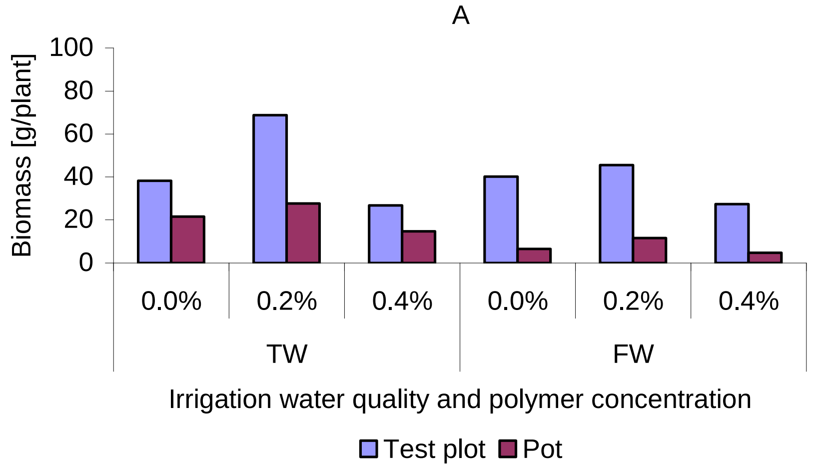


Figure A1: Element concentrations in 4 plant hole soil samples collected from the same test plot which amended with 0.2% SAP and irrigated with AWM; **A:** Ca, Fe, K and Mg. **B:** Mn, Na, P, S, Cu, Pb and Zn. Cd was below detection limit (0.05 mg/L)



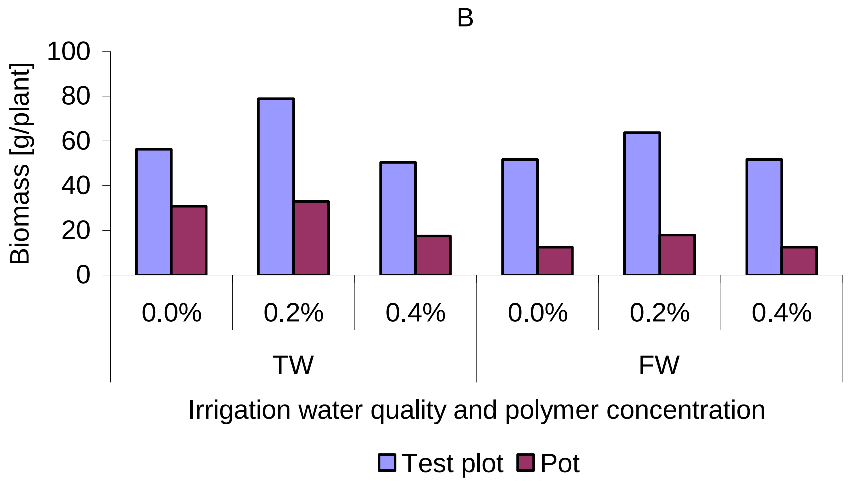
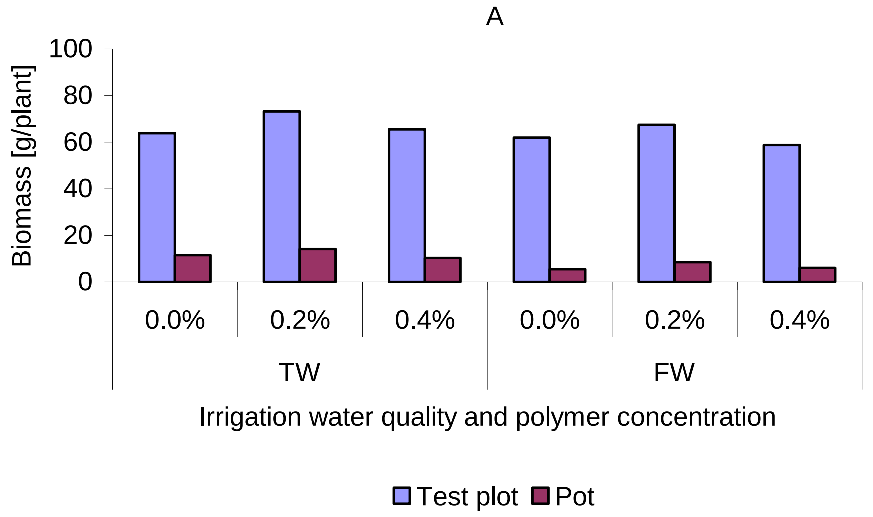


Figure A2: Biomass of eggplants in test plot and pot experiments from the year of 2010; grown in sandy soil amended with different concentrations of SAP and irrigated with treated wastewater and fresh water; **A:** Fruit, **B:** Leaves



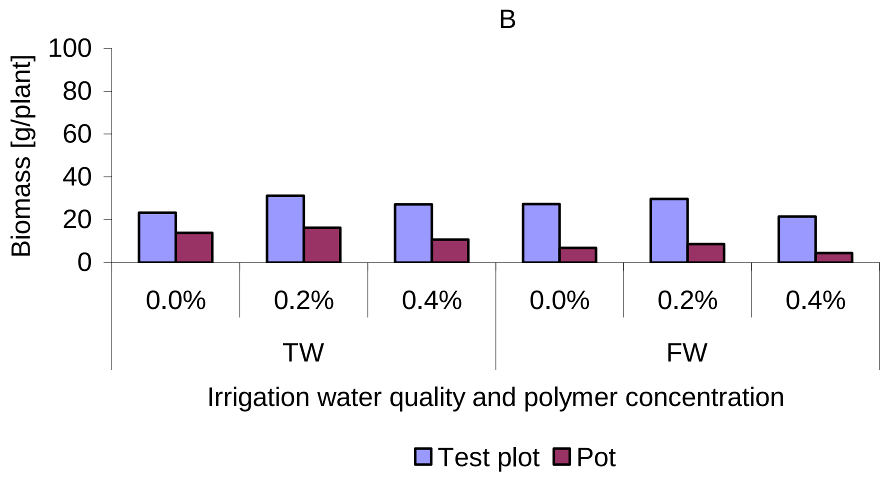
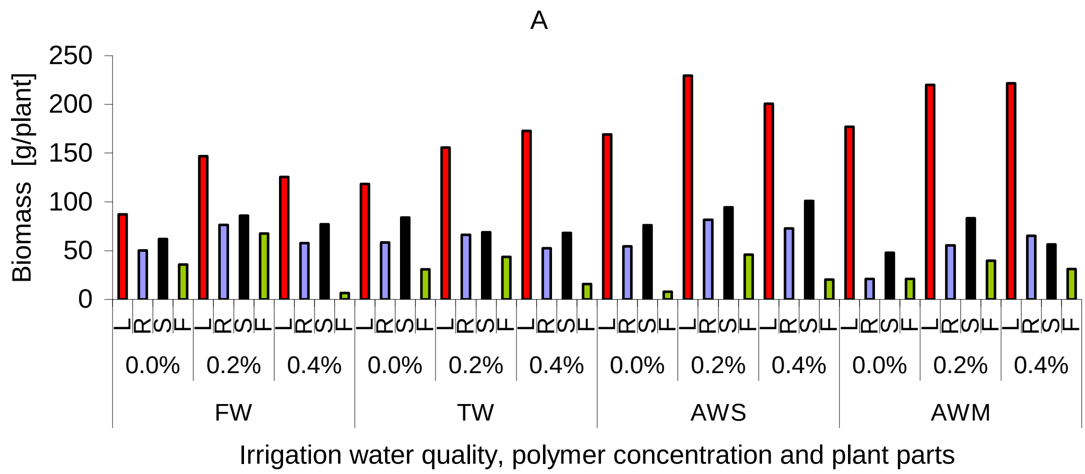


Figure A3: Biomass of eggplants in test plot and pot experiments from the year of 2010; grown in sandy soil amended with different concentrations of SAP and irrigated with treated wastewater and fresh water; **A:** Stem, **B:** Root



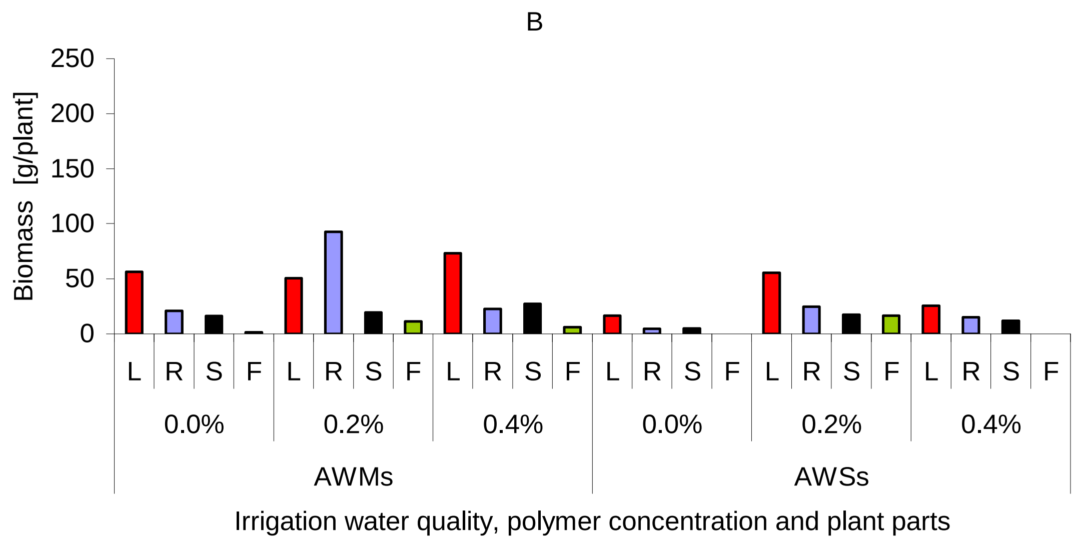


Figure A4: Biomass of eggplant parts in test plot and pot experiments; **A:** Test plot experiment, **B:** Pot experiment (L: leaves, R: roots, S: stem and F: fruits)

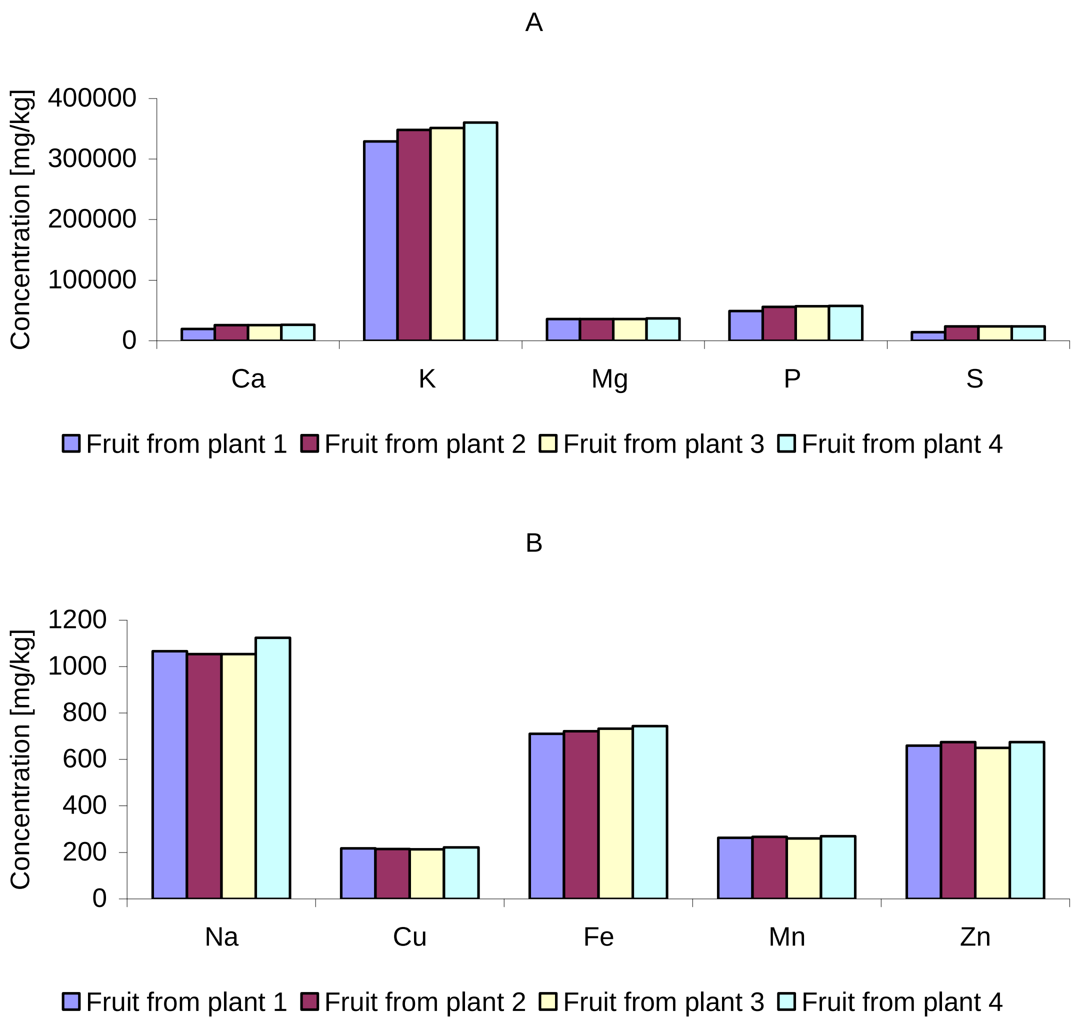
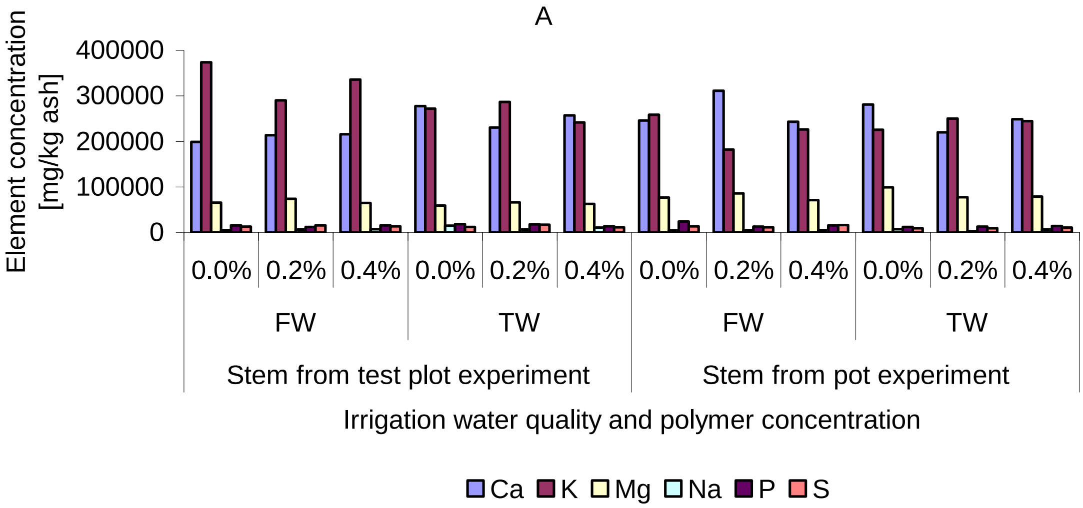


Figure A5: Element concentrations in 4 eggplant fruit samples collected from the same test plot which amended with 0.2% SAP and irrigated with AWM; **A:** Ca, K, Mg, P and S. **B:** Na, Cu, Fe, Mn and Zn. Cd and Pb were below detection limits (0.05 and 0.2 mg/L)



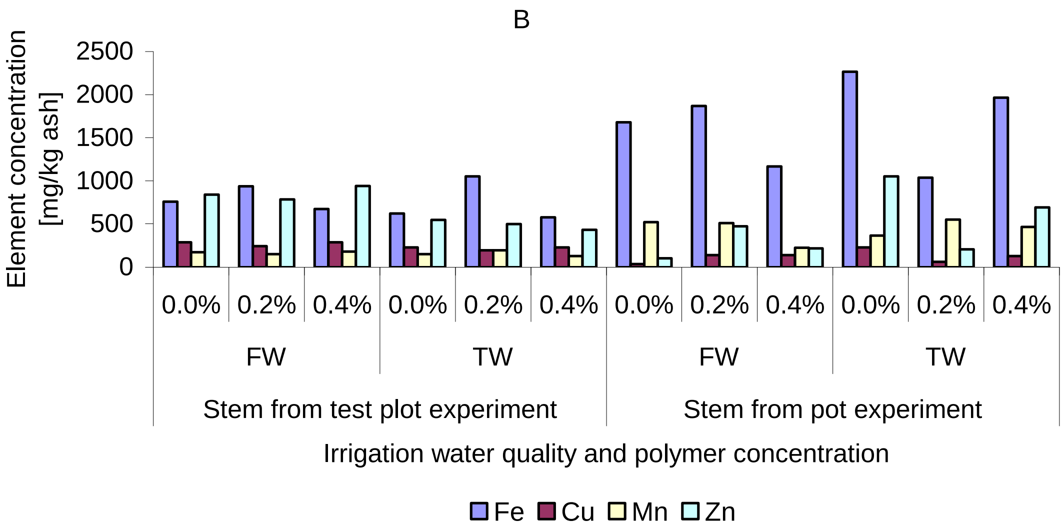


Figure A6: Effect of irrigation water quality and polymer concentration on the element concentrations in eggplant stem from the year 2010; **A:** Ca, K, Mg, Na, P and S., **B:** Fe, Cu, Mn and Zn. Cd and Pb were below detection limits (0.05 and 0.2 mg/L).

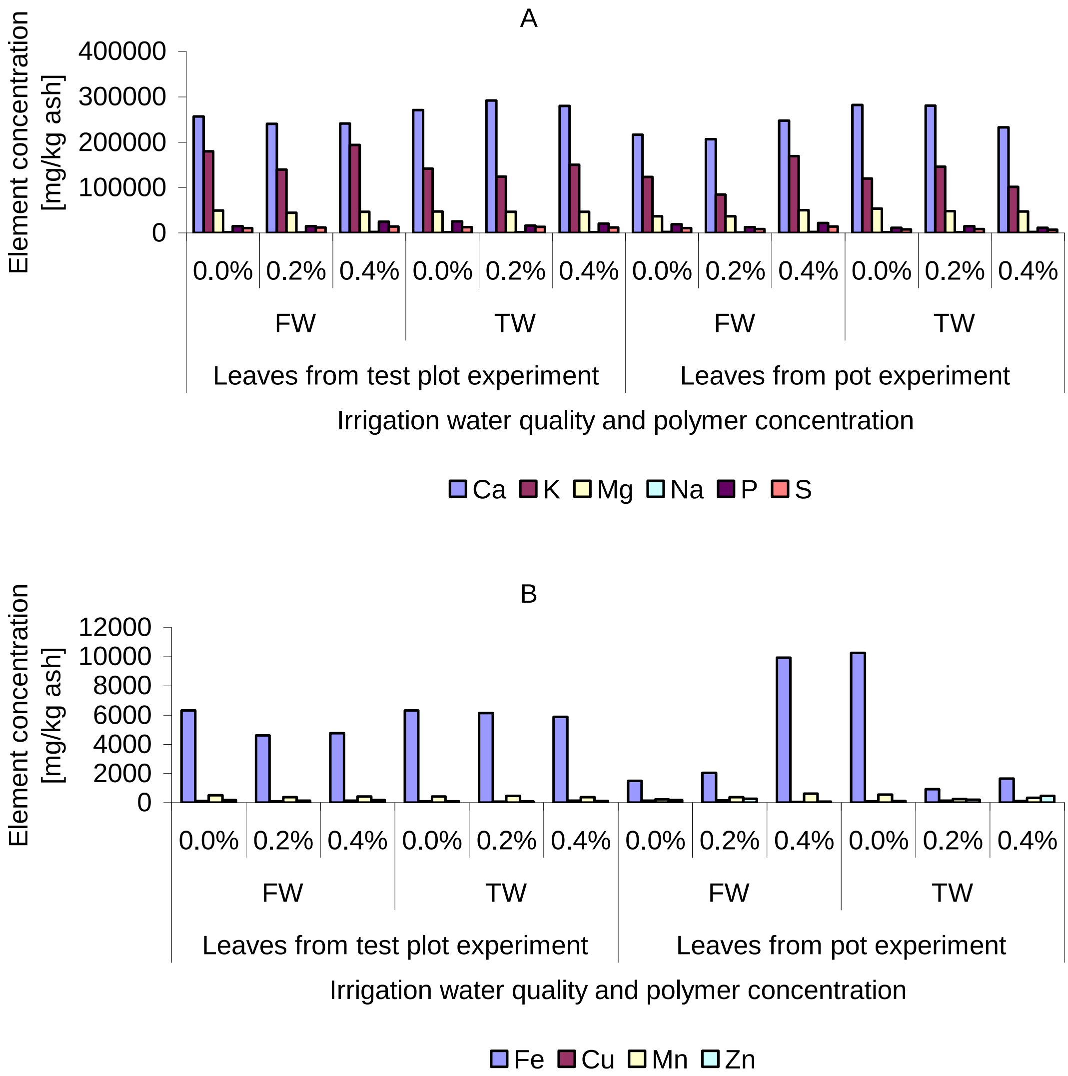
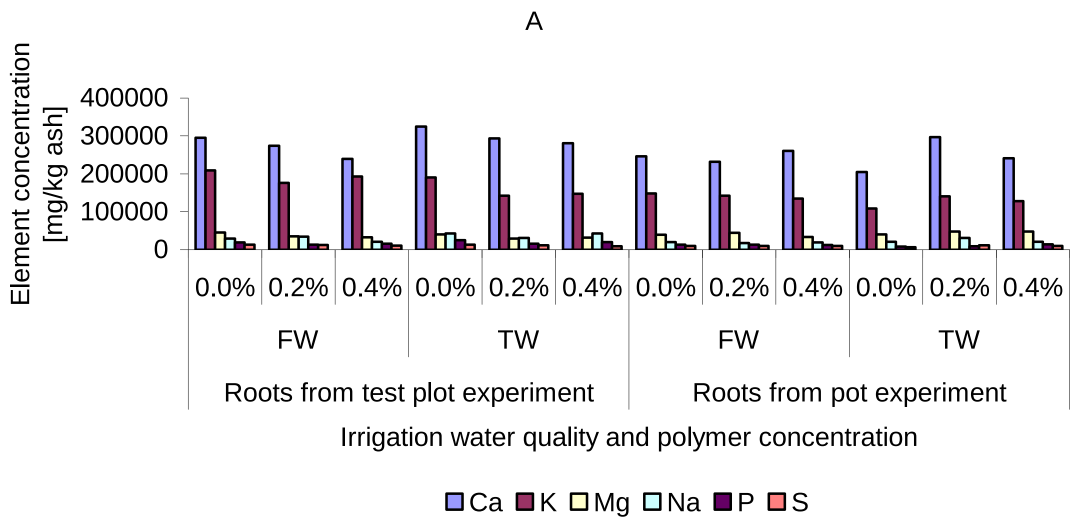


Figure A7: Effect of irrigation water quality and polymer concentration on the element concentrations in eggplant leaves from the year 2010; **A:** Ca, K, Mg, Na, P and S., **B:** Fe, Cu, Mn and Zn. Cd and Pb were below detection limits (0.05 and 0.2 mg/L).



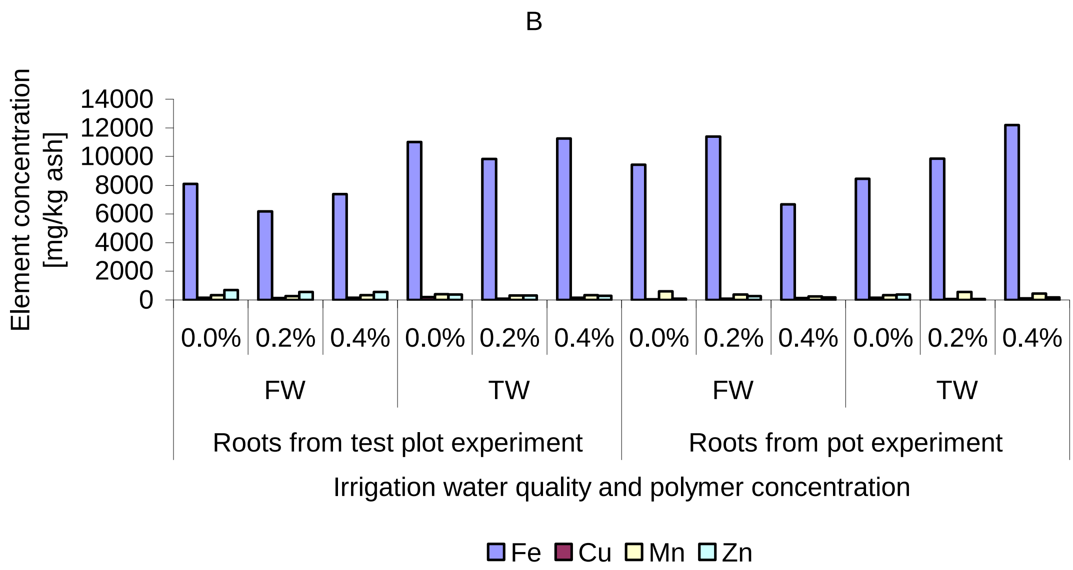
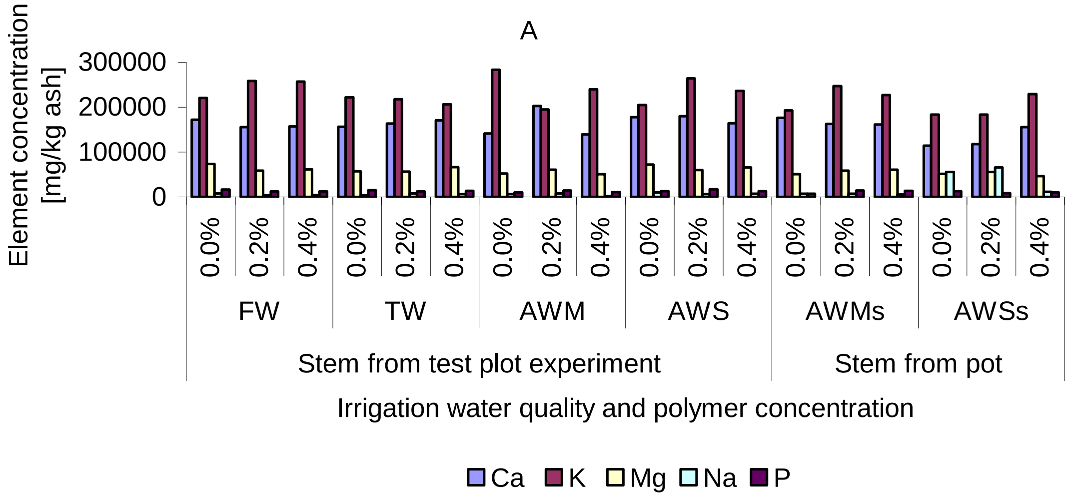


Figure A8: Effect of irrigation water quality and polymer concentration on the element concentrations in eggplant roots from the year 2010; **A:** Ca, K, Mg, Na, P and S., **B:** Fe, Cu, Mn and Zn. Cd and Pb were below detection limits (0.05 and 0.2 mg/L).



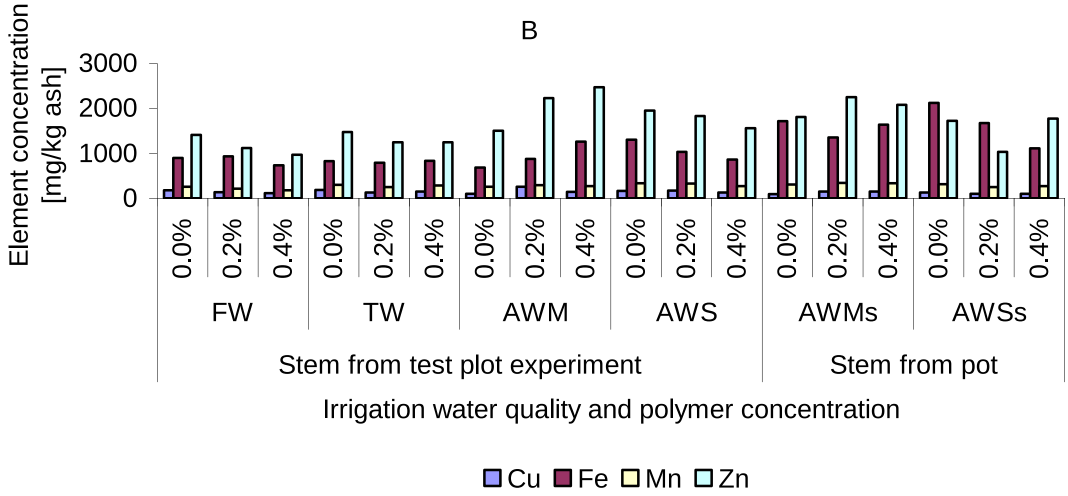
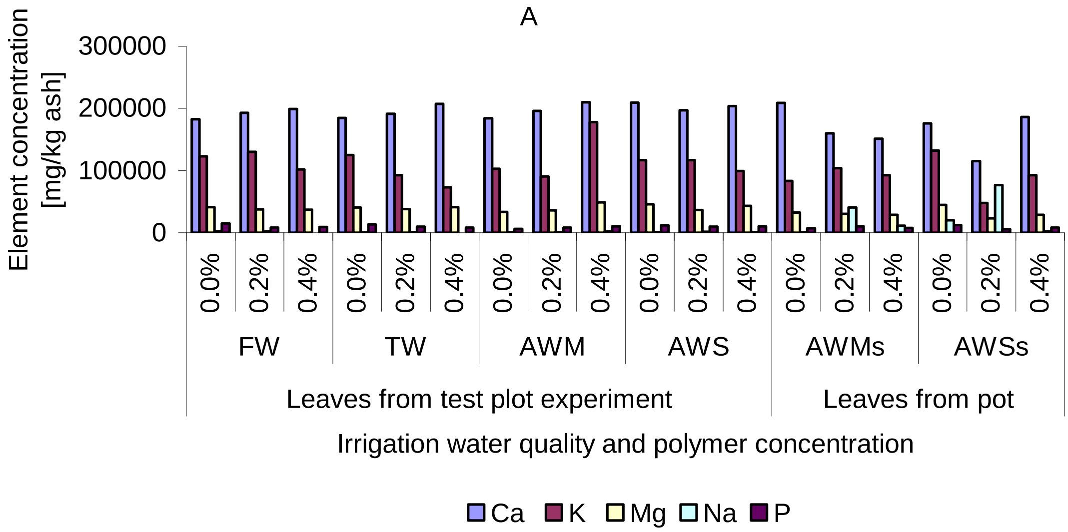


Figure A9: Effect of irrigation water quality and polymer concentration on the element concentrations in eggplant stem from the year 2011; **A:** Ca, K, Mg, Na, P and S., **B:** Cu, Fe, Mn and Zn. Cd and Pb were below detection limits (0.05 and 0.2 mg/L).



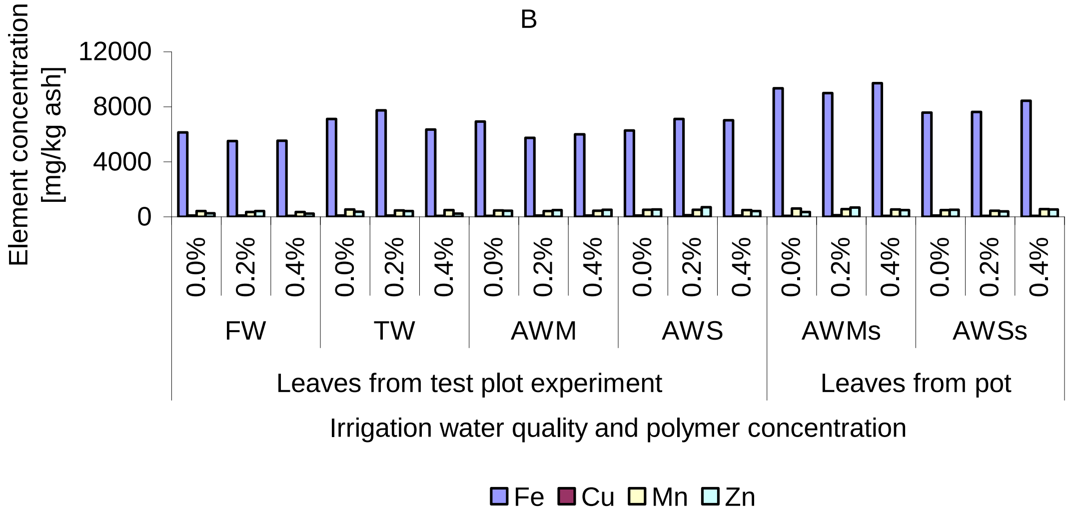


Figure A10: Effect of irrigation water quality and polymer concentration on the element concentrations in eggplant leaves from the year 2011; **A:** Ca, K, Mg, Na, P and S., **B:** Fe, Cu, Mn and Zn. Cd and Pb were below detection limits (0.05 and 0.2 mg/L).

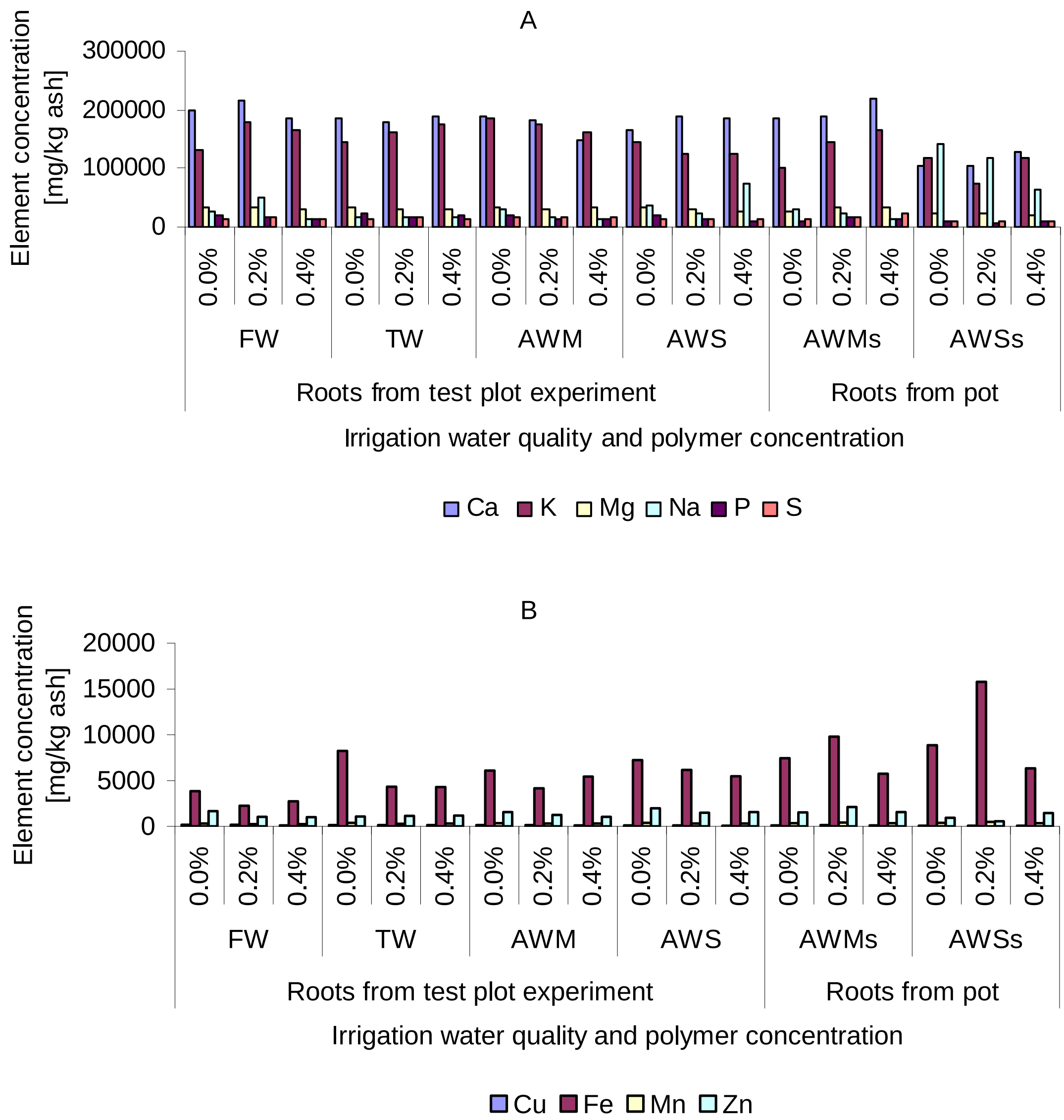


Figure A11: Effect of irrigation water quality and polymer concentration on the element concentrations in eggplant roots from the year 2011; **A:** Ca, K, Mg, Na, P and S., **B:** Cu, Fe, Mn and Zn. Cd and Pb were below detection limits (0.05 and 0.2 mg/L).

Table A1: Biochemical tests that carried out for the 7 bacterial isolates from treated wastewater

Isolate number	Catalase	Oxidase	Motility	SIM	Citrate	Urease	H_2S	Gas formation
1	+	weak	-	-	-	-	-	-
2	+	-	-	-	-	-	-	-
3	+	+	-	-	-	Weak positive	-	-
4	+	weak	-	-	-	-	-	-
5	+	weak	-	-	-	-	-	-
6	+	-	-	-	+	-	-	-
7	+	-	+	+	-	-	-	+

+: Positive, -: Negative

Urease +: pink, -: yellow color. SIM (indole) / motility +: pink, -: no change.

Citrate +: blue color, -: green color

Catalase +: production of bubbles, -: no change. Oxidase +: purple color, - : no change

H_2S +: blackish stain color, -: no change

Table A2: Identification for bacterial isolates from treated wastewater, cellular and colonial morphology

Sample Number	Gram stain	Cellular morphology	Colonial morphology	Name of bacteria
1	+	Non spore forming, V shape, Chine’s letters	Light white small colonies	*Corynebacterium diphtheriae*
2	-	Rod shape non spore forming	Non lactose fermentor	*Shigella sonnei*
3	-	Non spore forming, coccobacilli shape	Creamy colony, Mucoid colonies	*Klebsiella pneumoniae*
4	+	Non spore forming, V shape, Chine’s letters	Light white small colonies	*Corynebacterium diphtheriae*
5	+	Non spore forming, V shape, Chine’s letters	Light white small colonies	*Corynebacterium diphtheriae*
6	-	Non spore forming, Bacilli shape	Shiny small white colonies	*Enterobacter aerogenes*
7	-	Non spore forming, Bacilli shape	Small white colonies	*E. coli*

Curriculum vitae

Surname	AlTarawneh
First name	Amjad Asri Abed
Nationality	Jordanian
Place and date of birth	Karak, 9th June 1973
Marital status	Married (2 sons and 1 daughter)
Present position	PhD student, Institute of Environmental and Sustainable Chemistry, TU Braunschweig
Address of contact	Institute of Environmental and Sustainable Chemistry, TU Braunschweig, Hagenring 30, D-38106 Braunschweig, Germany. Tel: In Germany (004915222451083) In Jordan (00962795728669), (00962776287171) E-mail: (a.al-tarawneh@tu-bs.de), (amjtar@hotmail.com)

Education and degrees

1991-1995	B.Sc. Biology, Biology department, Faculty of Science, Mutah University, Al Karak, Jordan
2001-2004	M.Sc. Microbiology, College of Medical and Scientific Laboratory Technology, Sudan University of Science and Technology Khartoum, Sudan
2009-2012	PhD student, Institute of Environmental and Sustainable chemistry, Faculty of life Sciences, TU Braunschweig, Germany

Experiences

1. PhD Student at the Institute of Environmental and Sustainable Chemistry, TU Braunschweig, within Exceed Project since October 2009 until now. The PhD thesis is entitled: Impact of Soil Amended Superabsorbent Polymers on the Efficiency of Irrigation Measures in Jordanian Agriculture.

2. Research and teaching assistant and curator of Natural History Museum at Biology Department, Mutah University, since October 1997 until September 2009.

3. Research assistant at biological control of flies and mosquitoes project in Al-ghore area, supervised by Prof. Dr. Elias Saliba (University of Jordan) and Prof. Dr. Ratib Al- Oran (Mutah University); from April 1995 to July 1997.

Areas of Interest

1. Soil amendments
2. Reuse of treated wastewater for irrigation purposes
3. Bioremediation and bioaccumulation of heavy metals (metal uptake by bacteria).
4. Medicinal plants as antimicrobial agents.

Publications

1. Impact of soil amended superabsorbent polymers on the efficiency of irrigation measures in Jordanian agriculture, Eurosoil, 2-6 July, Bari, Italy, 2012.
2. Copper uptake by *Pseudomonas aeruginosa* isolated from infected burn patients. Current Microbiology, 59(3), 282-287, 2009.
3. Isolation and characterization of halophilic bacteria from the Dead Sea coast, Jordan. Advances in Environmental Biology, 2008.
4. Growth kinetics and toxicity of *Enterobacter cloacae* grown on linear alkylbenzene sulfonate as sole carbon source. Current Microbiology, 57(4), 364-370(7), 2008.
5. Variations in five species of Jordanian reptiles with new record on the land *Testudo floweri* (Testudinidae: Chelonia). Pakistan Journal of Zoology, 34(1), 43-49, 2002.
6. Using the normal benzene as a dermestidcide instead of Edulan-U. Second Conference of Biotechnology, Al al-Bayt University. 23-24 March, 1999.